Attorney Docket No. A8689

ANTI-IGF-I RECEPTOR ANTIBODY

[01] The present application is a continuation-in-part of parent application number 10/170,390, filed June 14, 2002, incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[02] The present invention relates to antibodies that bind to human insulin-like growth factor-I receptor (IGF-I receptor). More particularly, the invention relates to anti-IGF-I receptor antibodies that inhibit the cellular functions of the IGF-I receptor. Still more particularly, the invention relates to anti-IGF-I receptor antibodies that antagonize the effects of IGF-I, IGF-II and serum on the growth and survival of tumor cells and which are substantially devoid of agonist activity. The invention also relates to fragments of said antibodies, humanized and resurfaced versions of said antibodies, conjugates of said antibodies, antibody derivatives, and the uses of same in diagnostic, research and therapeutic applications. The invention further relates to improved antibodies or fragments thereof that are made from the above-described antibodies and fragments thereof. In another aspect, the invention relates to a polynucleotide encoding the antibodies or fragments thereof, and to vectors comprising the polynucleotides.

BACKGROUND OF THE INVENTION

[03] Insulin-like growth factor-I receptor (IGF-I receptor) is a transmembrane heterotetrameric protein, which has two extracellular alpha chains and two membrane-spanning beta chains in a disulfide-linked β–α–α–β configuration. The binding of the ligands, which are insulin-like growth-factor-I (IGF-I) and insulin-like growth factor-II (IGF-II), by the extracellular domain of IGF-I receptor activates its intracellular tyrosine kinase domain resulting

in autophosphorylation of the receptor and substrate phosphorylation. The IGF-I receptor is homologous to insulin receptor, having a high sequence similarity of 84% in the beta chain tyrosine kinase domain and a low sequence similarity of 48% in the alpha chain extracellular cysteine rich domain (Ulrich, A. et al., 1986, *EMBO*, 5, 2503-2512; Fujita-Yamaguchi, Y. et al., 1986, *J. Biol. Chem.*, 261, 16727-16731; LeRoith, D. et al., 1995, *Endocrine Reviews*, 16, 143-163). The IGF-I receptor and its ligands (IGF-I and IGF-II) play important roles in numerous physiological processes including growth and development during embryogenesis, metabolism, cellular proliferation and cell differentiation in adults (LeRoith, D., 2000, *Endocrinology*, 141, 1287-1288; LeRoith, D., 1997, *New England J. Med.*, 336, 633-640).

[04] IGF-I and IGF-II function both as endocrine hormones in the blood, where they are predominantly present in complexes with IGF-binding proteins, and as paracrine and autocrine growth factors that are produced locally (Humbel, R. E., 1990, *Eur. J. Biochem.*, 190, 445-462; Cohick, W. S. and Clemmons, D. R., 1993, *Annu. Rev. Physiol.* 55, 131-153).

[05] The IGF-I receptor has been implicated in promoting growth, transformation and survival of tumor cells (Baserga, R. et al., 1997, *Biochem. Biophys. Acta*, 1332, F105-F126; Blakesley, V. A. et al., 1997, *Journal of Endocrinology*, 152, 339-344; Kaleko, M., Rutter, W. J., and Miller, A. D. 1990, *Mol. Cell. Biol.*, 10, 464-473). Thus, several types of tumors are known to express higher than normal levels of IGF-I receptor, including breast cancer, colon cancer, ovarian carcinoma, synovial sarcoma and pancreatic cancer (Khandwala, H. M. et al., 2000, *Endocrine Reviews*, 21, 215-244; Werner, H. and LeRoith, D., 1996, *Adv. Cancer Res.*, 68,183-223; Happerfield, L. C. et al., 1997, *J. Pathol.*, 183, 412-417; Frier, S. et al., 1999, *Gut*, 44, 704-708; van Dam, P. A. et al., 1994, *J. Clin. Pathol.*, 47, 914-919; Xie, Y. et al., 1999, *Cancer Res.*, 59, 3588-3591; Bergmann, U. et al., 1995, *Cancer Res.*, 55, 2007-2011). *In vitro*, IGF-I and IGF-II

have been shown to be potent mitogens for several human tumor cell lines such as lung cancer, breast cancer, colon cancer, osteosarcoma and cervical cancer (Ankrapp, D. P. and Bevan, D. R., 1993, *Cancer Res.*, 53, 3399-3404; Cullen, K. J., 1990, *Cancer Res.*, 50, 48-53; Hermanto, U. et al., 2000, *Cell Growth & Differentiation*, 11, 655-664; Guo, Y. S. et al., 1995, *J. Am. Coll. Surg.*, 181, 145-154; Kappel, C. C. et al., 1994, *Cancer Res.*, 54, 2803-2807; Steller, M. A. et al., 1996, *Cancer Res.*, 56, 1761-1765). Several of these tumors and tumor cell lines also express high levels of IGF-I or IGF-II, which may stimulate their growth in an autocrine or paracrine manner (Quinn, K. A. et al., 1996, *J. Biol. Chem.*, 271, 11477-11483).

[06] Epidemiological studies have shown a correlation of elevated plasma level of IGF-I (and lower level of IGF-binding protein-3) with increased risk for prostate cancer, colon cancer, lung cancer and breast cancer (Chan, J. M. et al., 1998, *Science*, 279, 563-566; Wolk, A. et al., 1998, *J. Natl. Cancer Inst.*, 90, 911-915; Ma, J. et al., 1999, *J. Natl. Cancer Inst.*, 91, 620-625; Yu, H. et al., 1999, *J. Natl. Cancer Inst.*, 91, 151-156; Hankinson, S. E. et al., 1998, *Lancet*, 351, 1393-1396). Strategies to lower the IGF-I level in plasma or to inhibit the function of IGF-I receptor have been suggested for cancer prevention (Wu, Y. et al., 2002, *Cancer Res.*, 62, 1030-1035; Grimberg, A and Cohen P., 2000, *J. Cell. Physiol.*, 183, 1-9).

[07] The IGF-I receptor protects tumor cells from apoptosis caused by growth factor deprivation, anchorage independence or cytotoxic drug treatment (Navarro, M. and Baserga, R., 2001, *Endocrinology*, 142, 1073-1081; Baserga, R. et al., 1997, *Biochem. Biophys. Acta*, 1332, F105-F126). The domains of IGF-I receptor that are critical for its mitogenic, transforming and anti-apoptotic activities have been identified by mutational analysis.

[08] For example, the tyrosine 1251 residue of IGF-I receptor has been identified as critical for anti-apoptotic and transformation activities but not for its mitogenic activity (O'Connor, R. et

al., 1997, *Mol. Cell. Biol.*, 17, 427-435; Miura, M. et al., 1995, *J. Biol. Chem.*, 270, 22639-22644). The intracellular signaling pathway of ligand-activated IGF-I receptor involves phosphorylation of tyrosine residues of insulin receptor substrates (IRS-1 and IRS-2), which recruit phosphatidylinositol-3-kinase (PI-3-kinase) to the membrane. The membrane-bound phospholipid products of PI-3-kinase activate a serine/threonine kinase Akt, whose substrates include the pro-apoptotic protein BAD which is phosphorylated to an inactive state (Datta, S. R., Brunet, A. and Greenberg, M. E., 1999, *Genes & Development*, 13, 2905-2927; Kulik, G., Klippel, A. and Weber, M. J., 1997, *Mol. Cell. Biol.* 17, 1595-1606). The mitogenic signaling of IGF-I receptor in MCF-7 human breast cancer cells requires PI-3-kinase and is independent of mitogen-activated protein kinase, whereas the survival signaling in differentiated rat pheochromocytoma PC12 cells requires both PI-3-kinase and mitogen-activated protein kinase pathways (Dufourny, B. et al., 1997, *J. Biol. Chem.*, 272, 31163-31171; Parrizas, M., Saltiel, A. R. and LeRoith, D., 1997, *J. Biol. Chem.*, 272, 154-161).

[09] Down-regulation of IGF-I receptor level by anti-sense strategies has been shown to reduce the tumorigenicity of several tumor cell lines *in vivo* and *in vitro*, such as melanoma, lung carcinoma, ovarian cancer, glioblastoma, neuroblastoma and rhabdomyosarcoma (Resnicoff, M. et al., 1994, *Cancer Res.*, 54, 4848-4850; Lee, C.-T. et al., 1996, *Cancer Res.*, 56, 3038-3041; Muller, M. et al., 1998, *Int. J. Cancer*, 77, 567-571; Trojan, J. et al., 1993, *Science*, 259, 94-97; Liu, X. et al., 1998, *Cancer Res.*, 58, 5432-5438; Shapiro, D. N. et al., 1994, *J. Clin. Invest.*, 94, 1235-1242). Likewise, a dominant negative mutant of IGF-I receptor has been reported to reduce the tumorigenicity *in vivo* and growth *in vitro* of transformed Rat-1 cells overexpressing IGF-I receptor (Prager, D. et al., 1994, *Proc. Natl. Acad. Sci. USA*, 91, 2181-2185).

[10] Tumor cells expressing an antisense to the IGF-I receptor mRNA undergo massive apoptosis when injected into animals in biodiffusion chambers. This observation makes the IGF-I receptor an attractive therapeutic target, based upon the hypothesis that tumor cells are more susceptible than normal cells to apoptosis by inhibition of IGF-I receptor (Resnicoff, M. et al., 1995, *Cancer Res.*, 55, 2463-2469; Baserga, R., 1995, *Cancer Res.*, 55, 249-252).

[11] Another strategy to inhibit the function of IGF-I receptor in tumor cells has been to use anti-IGF-I receptor antibodies which bind to the extracellular domains of IGF-I receptor and inhibit its activation. Several attempts have been reported to develop mouse monoclonal antibodies against IGF-I receptor, of which two inhibitory antibodies - IR3 and 1H7 - are available and their use has been reported in several IGF-I receptor studies.

[12] The IR3 antibody was developed using a partially purified placental preparation of insulin receptor to immunize mice, which yielded an antibody, IR1, that was selective for binding insulin receptor, and two antibodies, IR2 and IR3, that showed preferential immunoprecipitation of IGF-I receptor (somatomedin-C receptor) but also weak immunoprecipitation of insulin receptor (Kull, F. C. et al., 1983, *J. Biol. Chem.*, 258, 6561-6566).

[13] The 1H7 antibody was developed by immunizing mice with purified placental preparation of IGF-I receptor, which yielded the inhibitory antibody 1H7 in addition to three stimulatory antibodies (Li, S.-L. et al., 1993, *Biochem. Biophys. Res. Commun.*, 196, 92-98; Xiong, L. et al., 1992, *Proc. Natl. Acad. Sci. USA*, 89, 5356-5360).

[14] In another report, a panel of mouse monoclonal antibodies specific for human IGF-I receptor were obtained by immunization of mice with transfected 3T3 cells expressing high levels of IGF-I receptor, which were categorized into seven groups by binding competition

studies and by their inhibition or stimulation of IGF-I binding to transfected 3T3 cells (Soos, M. A. et al., 1992, *J. Biol. Chem.*, 267, 12955-12963).

[15] Thus, although IR3 antibody is the most commonly used inhibitory antibody for IGF-I receptor studies *in vitro*, it suffers from the drawback that it exhibits agonistic activity in transfected 3T3 and CHO cells expressing human IGF-I receptor (Kato, H. et al., 1993, *J. Biol. Chem.*, 268, 2655-2661; Steele-Perkins, G. and Roth, R. A., 1990, *Biochem. Biophys. Res. Commun.*, 171, 1244-1251). Similarly, among the panel of antibodies developed by Soos et al., the most inhibitory antibodies 24-57 and 24-60 also showed agonistic activities in the transfected 3T3 cells (Soos, M. A. et al., 1992, *J. Biol. Chem.*, 267, 12955-12963). Although, IR3 antibody is reported to inhibit the binding of IGF-I (but not IGF-II) to expressed receptors in intact cells and after solubilization, it is shown to inhibit the ability of both IGF-I and IGF-II to stimulate DNA synthesis in cells *in vitro* (Steele-Perkins, G. and Roth, R. A., 1990, *Biochem. Biophys. Res. Commun.*, 171, 1244-1251). The binding epitope of IR3 antibody has been inferred from chimeric insulin-IGF-I receptor constructs to be the 223-274 region of IGF-I receptor (Gustafson, T. A. and Rutter, W. J., 1990, *J. Biol. Chem.*, 265, 18663-18667; Soos, M. A. et al., 1992, *J. Biol. Chem.*, 267, 12955-12963).

[16] The MCF-7 human breast cancer cell line is typically used as a model cell line to demonstrate the growth response of IGF-I and IGF-II *in vitro* (Dufourny, B. et al., 1997, *J. Biol. Chem.*, 272, 31163-31171). In MCF-7 cells, the IR3 antibody incompletely blocks the stimulatory effect of exogenously added IGF-I and IGF-II in serum-free conditions by approximately 80%. Also, the IR3 antibody does not significantly inhibit (less than 25%) the growth of MCF-7 cells in 10% serum (Cullen, K. J. et al., 1990, *Cancer Res.*, 50, 48-53). This weak inhibition of serum-stimulated growth of MCF-7 cells by IR3 antibody *in vitro* may be

related to the results of an *in vivo* study in which IR3 antibody treatment did not significantly inhibit the growth of a MCF-7 xenograft in nude mice (Arteaga, C. L. et al., 1989, *J. Clin. Invest.*, 84, 1418-1423).

[17] Because of the weak agonistic activities of the IR3 and other reported antibodies, and their inability to significantly inhibit the growth of tumor cells such as MCF-7 cells in the more physiological condition of serum-stimulation (instead of stimulation by exogenously added IGF-I or IGF-II in serum-free condition), there is a need for new anti-IGF-I receptor antibodies which significantly inhibit the serum-stimulated growth of tumor cells but which do not show significant agonistic activity by themselves.

SUMMARY OF THE INVENTION

[18] Accordingly, it is an object of the invention to provide antibodies, antibody fragments and antibody derivatives that specifically bind to insulin-like growth factor-I receptor and inhibit the cellular activity of the receptor by antagonizing the receptor, and are also substantially devoid of agonist activity towards the receptor.

[19] Thus, in a first embodiment, there is provided murine antibody EM164, which is fully characterized herein with respect to the amino acid sequences of both its light and heavy chain variable regions, the cDNA sequences of the genes for the light and heavy chain variable regions, the identification of its CDRs (complementarity-determining regions), the identification of its surface amino acids, and means for its expression in recombinant form.

[20] In a second embodiment, there are provided resurfaced or humanized versions of antibody EM164 wherein surface-exposed residues of the antibody or its fragments are replaced in both light and heavy chains to more closely resemble known human antibody surfaces. Such

humanized antibodies may have increased utility, compared to murine EM164, as therapeutic or diagnostic agents. Humanized versions of antibody EM164 are also fully characterized herein with respect to their respective amino acid sequences of both light and heavy chain variable regions, the DNA sequences of the genes for the light and heavy chain variable regions, the identification of the CDRs, the identification of their surface amino acids, and disclosure of a means for their expression in recombinant form.

[21] In a third embodiment, there is provided an antibody that is capable of inhibiting the growth of a cancer cell by greater than about 80% in the presence of a growth stimulant such as, for example, serum, insulin-like growth factor-I and insulin-like growth factor-II.

[22] In a fourth embodiment, there is provided an antibody or antibody fragment having a heavy chain including CDRs having amino acid sequences represented by SEQ ID NOS:1-3, respectively:

SYWMH (SEQ ID NO:1),

EINPSNGRTNYNEKFKR (SEQ ID NO:2),

GRPDYYGSSKWYFDV (SEQ ID NO:3);

and having a light chain that comprises CDRs having amino acid sequences represented by SEQ ID NOS:4-6:

RSSQSIVHSNVNTYLE (SEQ ID NO:4);

KVSNRFS (SEQ ID NO:5);

FQGSHVPPT (SEQ ID NO:6).

[23] In a fifth embodiment, there are provided antibodies having a heavy chain that has an amino acid sequence that shares at least 90% sequence identity with an amino acid sequence represented by SEQ ID NO:7:

QVQLQQSGAELVKPGASVKLSCKASGYTFTSYWMHWVKQRPGQGLEWIGEINP
SNGRTNYNEKFKRKATLTVDKSSSTAYMQLSSLTSEDSAVYYFARGRPDYYGSS
KWYFDVWGAGTTVTVSS (SEQ ID NO:7).

[24] Similarly, there are provided antibodies having a light chain that has an amino acid sequence that shares at least 90% sequence identity with an amino acid sequence represented by SEQ ID NO:8:

DVLMTQTPLSLPVSLGDQASISCRSSQSIVHSNVNTYLEWYLQKPGQSPKLLIYK
VSNRFSGVPDRFSGSGSGTDFTLRISRVEAEDLGIYYCFQGSHVPPTFGGGTKLEI
KR (SEQ ID NO:8).

[25] In a sixth embodiment, antibodies are provided having a humanized or resurfaced light chain variable region having an amino acid sequence corresponding to one of SEQ ID NOS:- 9-12:

DVVMTQTPLSLPVSLGDPASISCRSSQSIVHSNVNTYLEWYLQKPGQSPRLLIYKV
SNRFSGVPDRFSGSGAGTDFTLRISRVEAEDLGIYYCFQGSHVPPTFGGGTKLEIK
R (SEQ ID NO:9);

DVLMTQTPLSLPVSLGDPASISCRSSQSIVHSNVNTYLEWYLQKPGQSPKLLIYKV
SNRFSGVPDRFSGSGAGTDFTLRISRVEAEDLGIYYCFQGSHVPPTFGGGTKLEIK
R (SEQ ID NO:10);

DVLMTQTPLSLPVSLGDPASISCRSSQSIVHSNVNTYLEWYLQKPGQSPRLLIYKV
SNRFSGVPDRFSGSGAGTDFTLRISRVEAEDLGIYYCFQGSHVPPTFGGGTKLEIK
R (SEQ ID NO:11); or

DVVMTQTPLSLPVSLGDPASISCRSSQSIVHSNVNTYLEWYLQKPGQSPKLLIYK
VSNRFSGVPDRFSGSGAGTDFTLRISRVEAEDLGIYYCFQGSHVPPTFGGGTKLEI
KR (SEQ ID NO:12).

[26] Similarly, antibodies are provided having a humanized or resurfaced heavy chain variable region having an amino acid sequence corresponding to SEQ ID NO:13:

QVQLVQSGAEVVKPGASVKLSCKASGYTFTSYWMHWVKQRPGQGLEWIGEINP
SNGRTNYNQKFQGKATLTVDKSSSTAYMQLSSLTSEDSAVYYFARGRPDYYGSS
KWYFDVWGQGTTVTVSS (SEQ ID NO:13).

[27] In a seventh embodiment, antibodies or antibody fragments of the present invention are provided that have improved properties. For example, antibodies or antibody fragments having improved affinity for IGF-I-receptor are prepared by affinity maturation of an antibody or fragment of the present invention.

[28] The present invention further provides conjugates of said antibodies, wherein a cytotoxic agent is covalently attached, directly or via a cleavable or non-cleavable linker, to an antibody or epitope-binding fragment of an antibody of the present invention. In preferred embodiments, the cytotoxic agent is a taxol, a maytansinoid, CC-1065 or a CC-1065 analog.

[29] The present invention further provides for antibodies or fragments thereof that are further labeled for use in research or diagnostic applications. In preferred embodiments, the label is a radiolabel, a fluorophore, a chromophore, an imaging agent or a metal ion.

[30] A method for diagnosis is also provided in which said labeled antibodies or fragments are administered to a subject suspected of having a cancer, and the distribution of the label within the body of the subject is measured or monitored.

[31] In an eighth embodiment, the invention provides methods for the treatment of a subject having a cancer by administering an antibody, antibody fragment or antibody conjugate of the present invention, either alone or in combination with other cytotoxic or therapeutic agents. The cancer can be one or more of, for example, breast cancer, colon cancer, ovarian carcinoma, osteosarcoma, cervical cancer, prostate cancer, lung cancer, synovial carcinoma, pancreatic cancer, or other cancer yet to be determined in which IGF-I receptor levels are elevated.

[32] In a ninth embodiment, the invention provides methods for the treatment of a subject having a cancer by administering an antibody, antibody fragment or antibody conjugate of the present invention, either alone or in combination with other cytotoxic or therapeutic agents. In particular, preferred cytotoxic and therapeutic agents include docetaxel, paclitaxel, doxorubicin, epirubicin, cyclophosphamide, trastuzumab (Herceptin), capecitabine, tamoxifen, toremifene, letrozole, anastrozole, fulvestrant, exemestane, goserelin, oxaliplatin, carboplatin, cisplatin, dexamethasone, antide, bevacizumab (Avastin), 5-fluorouracil, leucovorin, levamisole, irinotecan, etoposide, topotecan, gemcitabine, vinorelbine, estramustine, mitoxantrone, abarelix, zoledronate, streptozocin, rituximab (Rituxan), idarubicin, busulfan, chlorambucil, fludarabine, imatinib, cytarabine, ibritumomab (Zevalin), tositumomab (Bexxar), interferon alpha-2b, melphalam, bortezomib (Velcade), altretamine, asparaginase, gefitinib (Iressa), erlonitib (Tarceva), anti-EGF receptor antibody (Cetuximab, Abx-EGF), and an epothilone. More preferably, the therapeutic agent is a platinum agent (such as carboplatin, oxaliplatin, cisplatin), a taxane (such as paclitaxel, docetaxel), gemcitabine, or camptothecin.

[33] The cancer can be one or more of, for example, breast cancer, colon cancer, ovarian carcinoma, osteosarcoma, cervical cancer, prostate cancer, lung cancer, synovial carcinoma, pancreatic cancer, melanoma, multiple myeloma, neuroblastoma, and rhabdomyosarcoma, or other cancer yet to be determined in which IGF-I receptor levels are elevated.

[34] In a tenth embodiment, the invention provides kits comprising one or more of the elements described herein, and instructions for the use of those elements. In a preferred embodiment, a kit of the present invention includes antibody, antibody fragment or conjugate of the invention, and a therapeutic agent. The instructions for this preferred embodiment include instructions for inhibiting the growth of a cancer cell using the antibody, antibody fragment or conjugate of the invention, and the therapeutic agent, and/or instructions for a method of treating a patient having a cancer using the antibody, antibody fragment or conjugate of the invention, and the therapeutic agent.

BRIEF DESCRIPTION OF THE FIGURES

[35] FIGURE 1 shows fluorescence activated cell sorting (FACS) analysis of the specific binding of purified EM164 antibody to cells overexpressing human Y1251F IGF-I receptor or human insulin receptor.

[36] FIGURE 2 shows a binding titration curve for the binding of EM164 antibody to biotinylated human IGF-I receptor.

[37] FIGURE 3 shows the inhibition of the binding of biotinylated IGF-I to human breast cancer MCF-7 cells by EM164 antibody.

[38] FIGURE 4 shows the inhibition of IGF-I-stimulated autophosphorylation of IGF-I receptor in MCF-7 cells by EM164 antibody.

[39] FIGURE 5 shows the inhibition of IGF-I-stimulated IRS-1-phosphorylation in MCF-7 cells by EM164 antibody.

[40] FIGURE 6 shows the inhibition of IGF-I-stimulated signal transduction in SaOS-2 cells by EM164 antibody.

[41] FIGURE 7 shows the effect of EM164 antibody on the growth and survival of MCF-7 cells under different growth conditions, as assessed by MTT assay.

[42] FIGURE 8 shows the effect of EM164 antibody on the growth and survival of MCF-7 cells in the presence of various serum concentrations.

[43] FIGURE 9 shows the inhibition of IGF-I- and serum-stimulated growth and survival of NCI-H838 cells by EM164 antibody.

[44] FIGURE 10 shows the effect of treatment with EM164 antibody, taxol, or a combination of EM164 antibody and taxol, on the growth of a Calu-6 lung cancer xenograft in mice.

[45] FIGURE 11 shows competition between the binding of humanized EM164 antibody (v.1.0) and murine EM164 antibody.

[46] FIGURE 12 shows the cDNA (SEQ ID NO:49) and amino acid sequences (SEQ ID NO:50) of the light chain leader and variable region of the murine anti-IGF-I receptor antibody EM164. The arrow marks the start of framework 1. The 3 CDR sequences according to Kabat are underlined.

[47] FIGURE 13 shows the cDNA (SEQ ID NO:51) and amino acid sequences (SEQ ID NO:52) of the heavy chain leader and variable region for the murine anti-IGF-I receptor antibody EM164. The arrow marks the start of framework 1. The 3 CDR sequences according to Kabat are underlined.

[48] FIGURE 14 shows the light and heavy chain CDR amino acid sequences of antibody EM164 as determined from Chothia canonical class definitions. AbM modeling software definitions for the heavy chain CDRs are also shown. Light Chain: CDR1 is SEQ ID NO:4, CDR2 is SEQ ID NO:5, and CDR3 is SEQ ID NO:6. Heavy Chain: CDR1 is SEQ ID NO:1, CDR2 is SEQ ID NO:2, and CDR3 is SEQ ID NO:3. AbM Heavy Chain: CDR1 is SEQ ID NO:53, CDR2 is SEQ ID NO:54, and CDR3 is SEQ ID NO:55.

[49] FIGURE 15 shows the light chain and heavy chain amino acid sequences for anti-IGF-I-receptor antibody EM164 aligned with the germline sequences for the Cr1 (SEQ ID NO:56) and J558.c (SEQ ID NO:57) genes. Dashes (-) indicate sequence identity.

[50] FIGURE 16 shows the plasmids used to build and express the recombinant chimeric and humanized EM164 antibodies. A) a light chain cloning plasmid, B) a heavy chain cloning plasmid, C) a mammalian antibody expression plasmid.

[51] FIGURE 17 shows the 10 most homologous amino acid sequences of the light chains screened from the 127 antibodies in the set of structure files used to predict the surface residues of EM164. em164 LC (SEQ ID NO:58), 2jel (SEQ ID NO:59), 2pcp (SEQ ID NO:60), 1nqb (SEQ ID NO:61), 1kel (SEQ ID NO:62), 1hyx (SEQ ID NO:63), 1igf (SEQ ID NO:64), 1tet (SEQ ID NO:65), 1clz (SEQ ID NO:66), 1bln (SEQ ID NO:67), 1cly (SEQ ID NO:68), Consensus (SEQ ID NO:69).

[52] FIGURE 18 shows the 10 most homologous amino acid sequences of the heavy chains screened from the 127 antibodies in the set of structure files used to predict the surface residues of EM164. em164 HC (SEQ ID NO:70), 1nqb (SEQ ID NO:71), 1ngp (SEQ ID NO:72), 1fbi (SEQ ID NO:73), 1afv (SEQ ID NO:74), 1yuh (SEQ ID NO:75), 1plg (SEQ ID NO:76), 1d5b

(SEQ ID NO:77), 1ae6 (SEQ ID NO:78), 1axs (SEQ ID NO:79), 3hfl (SEQ ID NO:80), Consensus (SEQ ID NO:81).

[53] FIGURE 19 shows the average accessibility for each of the (A) light, and (B) heavy chain variable region residues from the 10 most homologous structures. The numbers represent the Kabat antibody sequence position numbers.

[54] FIGURE 20 shows the light chain variable region amino acid sequences for murine EM164 (muEM164) and humanized EM164 (huEM164) antibodies. muEM164 (SEQ ID NO:82), huEM164 V1.0 (SEQ ID NO:83), huEM164 V1.1 (SEQ ID NO:84), huEM164 V1.2 (SEQ ID NO:85), huEM164 V1.3 (SEQ ID NO:86).

[55] FIGURE 21 shows the heavy chain variable region amino acid sequences for murine (muEM164, SEQ ID NO:87) and humanized EM164 antibodies (huEM164, SEQ ID NO:88).

[56] FIGURE 22 shows the huEM164 v1.0 variable region DNA and amino acid sequences for both the light (DNA, SEQ ID NO:89, amino acid SEQ ID NO:90) and heavy chains (DNA, SEQ ID NO:91, amino acid SEQ ID NO:92).

[57] FIGURE 23 shows the light chain variable region DNA and amino acid sequences for humanized EM164 v1.1 (DNA, SEQ ID NO:93; amino acid SEQ ID NO:94), v1.2 (DNA, SEQ ID NO:95; amino acid SEQ ID NO:96) and v1.3 (DNA, SEQ ID NO:97; amino acid SEQ ID NO:98).

[58] FIGURE 24 shows the inhibition of IGF-I-stimulated growth and survival of MCF-7 cells by humanized EM164 v1.0 antibody and murine EM164 antibody.

[59] FIGURE 25 shows that EM164 suppresses IGF-1-stimulated cycling of MCF-7 cells.

[60] FIGURE 26 shows that EM164 suppresses the anti-apoptotic effect of IGF-1 and serum. Treatment with EM164 results in apoptotic cell death as demonstrated by the increased levels of cleaved CK18 protein.

[61] FIGURE 27 shows the effect of treatment with EM164 antibody, gemcitabine, or a combination of EM164 antibody and gemcitabine, on the growth of human BxPC-3 pancreatic cancer xenografts in immunodeficient mice.

DETAILED DESCRIPTION OF THE INVENTION

[62] The present inventors have discovered and improved novel antibodies that specifically bind to the human insulin-like growth factor-I receptor (IGF-IR) on the cell surface. The antibodies and fragments have the unique ability to inhibit the cellular functions of the receptor without the capacity to activate the receptor themselves. Thus, while previously known antibodies that specifically bind and inhibit IGF-IR also activate the receptor even in the absence of IGF-IR ligands, the antibodies or fragments of the present invention antagonize IGF-IR but are substantially devoid of agonist activity. Furthermore, the antibodies and antibody fragments of the present invention inhibit the growth of human tumor cells such as MCF-7 cells in the presence of serum by greater than 80%, which is a higher degree of inhibition than is obtained using previously known anti-IGF-IR antibodies.

[63] The present invention proceeds from a murine anti-IGF-IR antibody, herein EM164, that is fully characterized with respect to the amino acid sequences of both light and heavy chains, the identification of the CDRs, the identification of surface amino acids, and means for its expression in recombinant form.

[64] The germline sequences are shown in Figure 15 aligned with the sequence of EM164. The comparison identifies probable somatic mutations in EM164, including one each in CDR1 in the light chain and in CDR2 in the heavy chain.

[65] The primary amino acid and DNA sequences of antibody EM164 light and heavy chains, and of humanized versions, are disclosed herein. However, the scope of the present invention is not limited to antibodies and fragments comprising these sequences. Instead, all antibodies and fragments that specifically bind to an insulin-like growth factor-I receptor and antagonize the biological activity of the receptor, but which are substantially devoid of agonist activity, fall within the scope of the present invention. Thus, antibodies and antibody fragments may differ from antibody EM164 or the humanized derivatives in the amino acid sequences of their scaffold, CDRs, light chain and heavy chain, and still fall within the scope of the present invention.

[66] The CDRs of antibody EM164 are identified by modeling and their molecular structures have been predicted. Again, while the CDRs are important for epitope recognition, they are not essential to the antibodies and fragments of the invention. Accordingly, antibodies and fragments are provided that have improved properties produced by, for example, affinity maturation of an antibody of the present invention.

[67] Diverse antibodies and antibody fragments, as well as antibody mimics may be readily produced by mutation, deletion and/or insertion within the variable and constant region sequences that flank a particular set of CDRs. Thus, for example, different classes of Ab are possible for a given set of CDRs by substitution of different heavy chains, whereby, for example, IgG1-4, IgM, IgA1-2, IgD, IgE antibody types and isotypes may be produced. Similarly, artificial antibodies within the scope of the invention may be produced by embedding a given set

of CDRs within an entirely synthetic framework. The term "variable" is used herein to describe certain portions of the variable domains that differ in sequence among antibodies and are used in the binding and specificity of each particular antibody for its antigen. However, the variability is not usually evenly distributed through the variable domains of the antibodies. It is typically concentrated in three segments called complementarity determining regions (CDRs) or hypervariable regions both in the light chain and the heavy chain variable domains. The more highly conserved portions of the variable domains are called the framework (FR). The variable domains of heavy and light chains each comprise four framework regions, largely adopting a beta-sheet configuration, connected by three CDRs, which form loops connecting, and in some cases forming part of the beta-sheet structure. The CDRs in each chain are held together in close proximity by the FR regions and, with the CDRs from the other chain, contribute to the formation of the antigen binding site of antibodies (E. A. Kabat et al. *Sequences of Proteins of Immunological Interest*, fifth edition, 1991, NIH). The constant domains are not involved directly in binding an antibody to an antigen, but exhibit various effector functions, such as participation of the antibody in antibody-dependent cellular toxicity.

[68] Humanized antibodies, or antibodies adapted for non-rejection by other mammals, may be produced using several technologies such as resurfacing and CDR grafting. In the resurfacing technology, molecular modeling, statistical analysis and mutagenesis are combined to adjust the non-CDR surfaces of variable regions to resemble the surfaces of known antibodies of the target host. Strategies and methods for the resurfacing of antibodies, and other methods for reducing immunogenicity of antibodies within a different host, are disclosed in US Patent 5,639,641, which is hereby incorporated in its entirety by reference. In the CDR grafting technology, the murine heavy and light chain CDRs are grafted into a fully human framework sequence.

[69] The invention also includes functional equivalents of the antibodies described in this specification. Functional equivalents have binding characteristics that are comparable to those of the antibodies, and include, for example, chimerized, humanized and single chain antibodies as well as fragments thereof. Methods of producing such functional equivalents are disclosed in PCT Application WO 93/21319, European Patent Application No. 239,400; PCT Application WO 89/09622; European Patent Application 338,745; and European Patent Application EP 332,424, which are incorporated in their respective entireties by reference.

[70] Functional equivalents include polypeptides with amino acid sequences substantially the same as the amino acid sequence of the variable or hypervariable regions of the antibodies of the invention. "Substantially the same" as applied to an amino acid sequence is defined herein as a sequence with at least about 90%, and more preferably at least about 95% sequence identity to another amino acid sequence, as determined by the FASTA search method in accordance with Pearson and Lipman, Proc. Natl. Acad. Sci. USA 85, 2444-2448 (1988).

[71] Chimerized antibodies preferably have constant regions derived substantially or exclusively from human antibody constant regions and variable regions derived substantially or exclusively from the sequence of the variable region from a mammal other than a human. Humanized forms of the antibodies are made by substituting the complementarity determining regions of, for example, a mouse antibody, into a human framework domain, e.g., see PCT Pub. No. W092/22653. Humanized antibodies preferably have constant regions and variable regions other than the complementarity determining regions (CDRs) derived substantially or exclusively from the corresponding human antibody regions and CDRs derived substantially or exclusively from a mammal other than a human.

[72] Functional equivalents also include single-chain antibody fragments, also known as single-chain antibodies (scFvs). These fragments contain at least one fragment of an antibody variable heavy-chain amino acid sequence (V_H) tethered to at least one fragment of an antibody variable light-chain sequence (V_L) with or without one or more interconnecting linkers. Such a linker may be a short, flexible peptide selected to assure that the proper three-dimensional folding of the (V_L) and (V_H) domains occurs once they are linked so as to maintain the target molecule binding-specificity of the whole antibody from which the single-chain antibody fragment is derived. Generally, the carboxyl terminus of the (V_L) or (V_H) sequence may be covalently linked by such a peptide linker to the amino acid terminus of a complementary (V_L) and (V_H) sequence. Single-chain antibody fragments may be generated by molecular cloning, antibody phage display library or similar techniques. These proteins may be produced either in eukaryotic cells or prokaryotic cells, including bacteria.

[73] Single-chain antibody fragments contain amino acid sequences having at least one of the variable or complementarity determining regions (CDRs) of the whole antibodies described in this specification, but are lacking some or all of the constant domains of those antibodies. These constant domains are not necessary for antigen binding, but constitute a major portion of the structure of whole antibodies. Single-chain antibody fragments may therefore overcome some of the problems associated with the use of antibodies containing a part or all of a constant domain. For example, single-chain antibody fragments tend to be free of undesired interactions between biological molecules and the heavy-chain constant region, or other unwanted biological activity. Additionally, single-chain antibody fragments are considerably smaller than whole antibodies and may therefore have greater capillary permeability than whole antibodies, allowing single-chain antibody fragments to localize and bind to target antigen-binding sites more efficiently.

Also, antibody fragments can be produced on a relatively large scale in prokaryotic cells, thus facilitating their production. Furthermore, the relatively small size of single-chain antibody fragments makes them less likely to provoke an immune response in a recipient than whole antibodies.

[74] Functional equivalents further include fragments of antibodies that have the same, or comparable binding characteristics to those of the whole antibody. Such fragments may contain one or both Fab fragments or the $F(ab')_2$ fragment. Preferably the antibody fragments contain all six complementarity determining regions of the whole antibody, although fragments containing fewer than all of such regions, such as three, four or five CDRs, are also functional. Further, the functional equivalents may be or may combine members of any one of the following immunoglobulin classes: IgG, IgM, IgA, IgD, or IgE, and the subclasses thereof.

[75] The knowledge of the amino acid and nucleic acid sequences for the anti-IGF-I receptor antibody EM164 and its humanized variants, which are described herein, can be used to develop other antibodies which also bind to human IGF-I receptor and inhibit the cellular functions of the IGF-I receptor. Several studies have surveyed the effects of introducing one or more amino acid changes at various positions in the sequence of an antibody, based on the knowledge of the primary antibody sequence, on its properties such as binding and level of expression (Yang, W. P. et al., 1995, *J. Mol. Biol.*, 254, 392-403; Rader, C. et al., 1998, *Proc. Natl. Acad. Sci. USA*, 95, 8910-8915; Vaughan, T. J. et al., 1998, *Nature Biotechnology*, 16, 535-539).

[76] In these studies, variants of the primary antibody have been generated by changing the sequences of the heavy and light chain genes in the CDR1, CDR2, CDR3, or framework regions, using methods such as oligonucleotide-mediated site-directed mutagenesis, cassette mutagenesis, error-prone PCR, DNA shuffling, or mutator-strains of *E. coli* (Vaughan, T. J. et al., 1998,

Nature Biotechnology, 16, 535-539; Adey, N. B. et al., 1996, Chapter 16, pp. 277-291, in *"Phage Display of Peptides and Proteins"*, Eds. Kay, B. K. et al., Academic Press). These methods of changing the sequence of the primary antibody have resulted in improved affinities of the secondary antibodies (Gram, H. et al., 1992, *Proc. Natl. Acad. Sci. USA*, 89, 3576-3580; Boder, E. T. et al., 2000, *Proc. Natl. Acad. Sci. USA*, 97, 10701-10705; Davies, J. and Riechmann, L., 1996, *Immunotechnolgy*, 2, 169-179; Thompson, J. et al., 1996, *J. Mol. Biol.*, 256, 77-88; Short, M. K. et al., 2002, *J. Biol. Chem.*, 277, 16365-16370; Furukawa, K. et al., 2001, *J. Biol. Chem.*, 276, 27622-27628).

[77] By a similar directed strategy of changing one or more amino acid residues of the antibody, the antibody sequences described in this invention can be used to develop anti-IGF-I receptor antibodies with improved functions.

[78] The conjugates of the present invention comprise the antibody, fragments, and their analogs as disclosed herein, linked to a cytotoxic agent. Preferred cytotoxic agents are maytansinoids, taxanes and analogs of CC-1065. The conjugates can be prepared by *in vitro* methods. In order to link the cytotoxic agent to the antibody, a linking group is used. Suitable linking groups are well known in the art and include disulfide groups, thioether groups, acid labile groups, photolabile groups, peptidase labile groups and esterase labile groups. Preferred linking groups are disulfide groups and thioether groups. For example, conjugates can be constructed using a disulfide exchange reaction or by forming a thioether bond between the antibody and the cytotoxic agent.

[79] Maytansinoids and maytansinoid analogs are among the preferred cytotoxic agents. Examples of suitable maytansinoids include maytansinol and maytansinol analogs. Suitable maytansinoids are disclosed in U.S. Patent Nos. 4,424,219; 4,256,746; 4,294,757; 4,307,016;

4,313,946; 4,315,929; 4,331,598; 4,361,650; 4,362,663; 4,364,866; 4,450,254; 4,322,348; 4,371,533; 6,333,410; 5,475,092; 5,585,499; and 5,846,545.

[80] Taxanes are also preferred cytotoxic agents. Taxanes suitable for use in the present invention are disclosed in U.S. Patent Nos. 6,372,738 and 6,340,701.

[81] CC-1065 and its analogs are also preferred cytotoxic drugs for use in the present invention. CC-1065 and its analogs are disclosed in U.S. Patent Nos. 6,372,738; 6,340,701; 5,846,545 and 5,585,499.

[82] An attractive candidate for the preparation of such cytotoxic conjugates is CC-1065, which is a potent anti-tumor antibiotic isolated from the culture broth of *Streptomyces zelensis*. CC-1065 is about 1000-fold more potent *in vitro* than are commonly used anti-cancer drugs, such as doxorubicin, methotrexate and vincristine (B.K. Bhuyan et al., *Cancer Res.*, **42**, 3532-3537 (1982)).

[83] Cytotoxic drugs such as methotrexate, daunorubicin, doxorubicin, vincristine, vinblastine, melphalan, mitomycin C, chlorambucil, and calicheamicin are also suitable for the preparation of conjugates of the present invention, and the drug molecules can also be linked to the antibody molecules through an intermediary carrier molecule such as serum albumin.

[84] For diagnostic applications, the antibodies of the present invention typically will be labeled with a detectable moiety. The detectable moiety can be any one which is capable of producing, either directly or indirectly, a detectable signal. For example, the detectable moiety may be a radioisotope, such as ^{3}H, ^{14}C, ^{32}P, ^{35}S, or ^{131}I; a fluorescent or chemiluminescent compound, such as fluorescein isothiocyanate, rhodamine, or luciferin; or an enzyme, such as alkaline phosphatase, beta-galactosidase or horseradish peroxidase.

[85] Any method known in the art for conjugating the antibody to the detectable moiety may be employed, including those methods described by Hunter, et al., Nature 144:945 (1962); David, et al., Biochemistry 13:1014 (1974); Pain, et al., J. Immunol. Meth. 40:219 (1981); and Nygren, J. Histochem. and Cytochem. 30:407 (1982).

[86] The antibodies of the present invention can be employed in any known assay method, such as competitive binding assays, direct and indirect sandwich assays, and immunoprecipitation assays (Zola, Monoclonal Antibodies: A Manual of Techniques, pp.147-158 (CRC Press, Inc., 1987)).

[87] The antibodies of the invention also are useful for *in vivo* imaging, wherein an antibody labeled with a detectable moiety such as a radio-opaque agent or radioisotope is administered to a subject, preferably into the bloodstream, and the presence and location of the labeled antibody in the host is assayed. This imaging technique is useful in the staging and treatment of malignancies. The antibody may be labeled with any moiety that is detectable in a host, whether by nuclear magnetic resonance, radiology, or other detection means known in the art.

[88] The antibodies of the invention also are useful as affinity purification agents. In this process, the antibodies are immobilized on a suitable support, such a Sephadex resin or filter paper, using methods well known in the art.

[89] The antibodies of the invention also are useful as reagents in biological research, based on their inhibition of the function of IGF-I receptor in cells.

[90] For therapeutic applications, the antibodies or conjugates of the invention are administered to a subject, in a pharmaceutically acceptable dosage form. They can be administered intravenously as a bolus or by continuous infusion over a period of time, by intramuscular, subcutaneous, intra-articular, intrasynovial, intrathecal, oral, topical, or inhalation

routes. The antibody may also be administered by intratumoral, peritumoral, intralesional, or perilesional routes, to exert local as well as systemic therapeutic effects. Suitable pharmaceutically acceptable carriers, diluents, and excipients are well known and can be determined by those of skill in the art as the clinical situation warrants. Examples of suitable carriers, diluents and/or excipients include: (1) Dulbecco's phosphate buffered saline, pH about 7.4, containing about 1 mg/ml to 25 mg/ml human serum albumin, (2) 0.9% saline (0.9% w/v NaCl), and (3) 5% (w/v) dextrose. The method of the present invention can be practiced *in vitro*, *in vivo*, or *ex vivo*.

[91] In other therapeutic treatments, the antibodies, antibody fragments or conjugates of the invention are co-administered, or administered sequentially, with one or more additional therapeutic agents. Suitable therapeutic agents include, but are not limited to, cytotoxic or cytostatic agents. Taxol is a preferred therapeutic agent that is also a cytotoxic agent.

[92] Cancer therapeutic agents are those agents that seek to kill or limit the growth of cancer cells while doing minimal damage to the host. Thus, such agents may exploit any difference in cancer cell properties (e.g. metabolism, vascularization or cell-surface antigen presentation) from healthy host cells. Differences in tumor morphology are potential sites for intervention: for example, the second therapeutic can be an antibody such as an anti-VEGF antibody that is useful in retarding the vascularization of the interior of a solid tumor, thereby slowing its growth rate. Other therapeutic agents include, but are not limited to, adjuncts such as granisetron HCl, androgen inhibitors such as leuprolide acetate, antibiotics such as doxorubicin, antiestrogens such as tamoxifen, antimetabolites such as interferon alpha-2a, cytotoxic agents such as taxol, enzyme inhibitors such as ras farnesyl-transferase inhibitor, immunomodulators such as aldesleukin, and nitrogen mustard derivatives such as melphalan HCl, and the like.

[93] The therapeutic agents that can be combined with EM164 for improved anti-cancer efficacy include diverse agents used in oncology practice (*Reference*: Cancer, Principles & Practice of Oncology, DeVita, V. T., Hellman, S., Rosenberg, S. A., 6th edition, Lippincott-Raven, Philadelphia, 2001), such as docetaxel, paclitaxel, doxorubicin, epirubicin, cyclophosphamide, trastuzumab (Herceptin), capecitabine, tamoxifen, toremifene, letrozole, anastrozole, fulvestrant, exemestane, goserelin, oxaliplatin, carboplatin, cisplatin, dexamethasone, antide, bevacizumab (Avastin), 5-fluorouracil, leucovorin, levamisole, irinotecan, etoposide, topotecan, gemcitabine, vinorelbine, estramustine, mitoxantrone, abarelix, zoledronate, streptozocin, rituximab (Rituxan), idarubicin, busulfan, chlorambucil, fludarabine, imatinib, cytarabine, ibritumomab (Zevalin), tositumomab (Bexxar), interferon alpha-2b, melphalam, bortezomib (Velcade), altretamine, asparaginase, gefitinib (Iressa), erlonitib (Tarceva), anti-EGF receptor antibody (Cetuximab, Abx-EGF), epothilones, and conjugates of cytotoxic drugs and antibodies against cell-surface receptors. Preferred therapeutic agents are platinum agents (such as carboplatin, oxaliplatin, cisplatin), taxanes (such as paclitaxel, docetaxel), gemcitabine, and camptothecin.

[94] The one or more additional therapeutic agents can be administered before, concurrently, or after the antibody, antibody fragment or conjugate of the invention. The skilled artisan will understand that for each therapeutic agent there may be advantages to a particular order of administration. Similarly, the skilled artisan will understand that for each therapeutic agent, the length of time between which the agent, and an antibody, antibody fragment or conjugate of the invention is administered, will vary.

[95] While the skilled artisan will understand that the dosage of each therapeutic agent will be dependent on the identity of the agent, the preferred dosages can range from about 10 mg/square

meter to about 2000 mg/square meter, more preferably from about 50 mg/square meter to about 1000 mg/square meter. For preferred agents such as platinum agents (carboplatin, oxaliplatin, cisplatin), the preferred dosage is about 10 mg/square meter to about 400 mg/square meter, for taxanes (paclitaxel, docetaxel) the preferred dosage is about 20 mg/square meter to about 150 mg/square meter, for gemcitabine the preferred dosage is about 100 mg/square meter to about 2000 mg/square meter, and for camptothecin the preferred dosage is about 50 mg/square meter to about 350 mg/square meter. The dosage of this and other therapeutic agents may depend on whether the antibody, antibody fragment or conjugate of the invention is administered concurrently or sequentially with a therapeutic agent.

[96] Administration of an antibody, antibody fragment or conjugate of the invention, and one or more additional therapeutic agents, whether co-administered or administered sequentially, may occur as described above for therapeutic applications. Suitable pharmaceutically acceptable carriers, diluents, and excipients for co-administration will be understood by the skilled artisan to depend on the identity of the particular therapeutic agent being co-administered.

[97] When present in an aqueous dosage form, rather than being lyophilized, the antibody typically will be formulated at a concentration of about 0.1 mg/ml to 100 mg/ml, although wide variation outside of these ranges is permitted. For the treatment of disease, the appropriate dosage of antibody or conjugate will depend on the type of disease to be treated, as defined above, the severity and course of the disease, whether the antibodies are administered for preventive or therapeutic purposes, the course of previous therapy, the patient's clinical history and response to the antibody, and the discretion of the attending physician. The antibody is suitably administered to the patient at one time or over a series of treatments.

[98] Depending on the type and severity of the disease, preferably from about 1 mg/square meter to about 2000 mg/square meter of antibody is an initial candidate dosage for administration to the patient, more preferably from about 10 mg/square meter to about 1000 mg/square meter of antibody whether, for example, by one or more separate administrations, or by continuous infusion. For repeated administrations over several days or longer, depending on the condition, the treatment is repeated until a desired suppression of disease symptoms occurs. However, other dosage regimens may be useful and are not excluded.

[99] The present invention also includes kits comprising one or more of the elements described herein, and instructions for the use of those elements. In a preferred embodiment, a kit of the present invention includes antibody, antibody fragment or conjugate of the invention, and a therapeutic agent. The instructions for this preferred embodiment include instructions for inhibiting the growth of a cancer cell using the antibody, antibody fragment or conjugate of the invention, and the therapeutic agent, and/or instructions for a method of treating a patient having a cancer using the antibody, antibody fragment or conjugate of the invention, and the therapeutic agent.

[100] Preferably, the antibody used in the kit has the same amino acid sequence as the murine antibody EM164 produced by mouse hybridoma EM164 (ATCC accession number PTA-4457), or the antibody is an epitope-binding fragment thereof, wherein both the antibody and the fragment specifically bind to insulin-like growth factor-I receptor. The antibody and antibody fragment used in the kit may also be a resurfaced version of the EM164 antibody, a humanized version of the EM164 antibody, or an altered version of the EM164 antibody having least one nucleotide mutation, deletion or insertion. Antibodies and antibody fragments of each of these three versions retain the same binding specificity as the EM164 antibody.

[101] Preferably, the therapeutic agent used in the kit is selected from the group consisting of docetaxel, paclitaxel, doxorubicin, epirubicin, cyclophosphamide, trastuzumab (Herceptin), capecitabine, tamoxifen, toremifene, letrozole, anastrozole, fulvestrant, exemestane, goserelin, oxaliplatin, carboplatin, cisplatin, dexamethasone, antide, bevacizumab (Avastin), 5-fluorouracil, leucovorin, levamisole, irinotecan, etoposide, topotecan, gemcitabine, vinorelbine, estramustine, mitoxantrone, abarelix, zoledronate, streptozocin, rituximab (Rituxan), idarubicin, busulfan, chlorambucil, fludarabine, imatinib, cytarabine, ibritumomab (Zevalin), tositumomab (Bexxar), interferon alpha-2b, melphalam, bortezomib (Velcade), altretamine, asparaginase, gefitinib (Iressa), erlonitib (Tarceva), anti-EGF receptor antibody (Cetuximab, Abx-EGF), and an epothilone. More preferably, the therapeutic agent is a platinum agent (such as carboplatin, oxaliplatin, cisplatin), a taxane (such as paclitaxel, docetaxel), gemcitabine, or camptothecin.

[102] The elements of the kits of the present invention are in a suitable form for a kit, such as a solution or lyophilized powder. The concentration or amount of the elements of the kits will be understood by the skilled artisan to varying depending on the identity and intended use of each element of the kit.

[103] The cancers and cells therefrom referred to in the instructions of the kits include breast cancer, colon cancer, ovarian carcinoma, osteosarcoma, cervical cancer, prostate cancer, lung cancer, synovial carcinoma, pancreatic cancer, melanoma, multiple myeloma, neuroblastoma, and rhabdomyosarcoma.

EXAMPLES

[104] The invention is now described by reference to the following examples, which are illustrative only, and are not intended to limit the present invention.

EXAMPLE 1: <u>Murine EM164 Antibody</u>

[105] In this first example, the complete primary amino acid structure and cDNA sequence of a murine antibody of the present invention is disclosed, together with its binding properties and means for its expression in recombinant form. Accordingly, there is provided a full and complete disclosure of an antibody of the invention and its preparation, such that one of ordinary skill in the immunological arts would be able to prepare said antibody without undue experimentation.

A. **Generation of Anti-IGF-I Receptor Monoclonal Antibody Hybridoma**

[106] A cell line expressing human IGF-I receptor with a Y1251F mutation was used for immunization as it expressed a high number of IGF-I receptors (~10^7 per cell). The Y1251F-mutation in the cytoplasmic domain of IGF-I receptor resulted in loss of transformation and anti-apoptotic signaling, but did not affect IGF-I binding and IGF-I-stimulated mitogenic signaling (O'Connor, R. et al., 1997, *Mol. Cell. Biol.*, 17, 427-435; Miura, M. et al., 1995, *J. Biol. Chem.*, 270, 22639-22644). The mutation did not otherwise affect antibody generation because the antibody of this example bound to the extracellular domain of IGF-I receptor, which was identical for both the Y1251F mutant and the wild type receptor.

[107] A cell line expressing human IGF-I receptor with a Y1251F mutation was generated from 3T3-like cells of a IGF-I-receptor-deficient mouse by transfection with Y1251F-mutant human IGF-I-receptor gene together with a puromycin-resistance gene, and was selected using puromycin (2.5 microgram/mL) and by FACS sorting for high IGF-I receptor expression (Miura, M. et al., 1995, *J. Biol. Chem.*, 270, 22639-22644). A cell line having a high level of IGF-I

receptor expression was further selected using a high concentration of puromycin such as 25 microgram/mL, which was toxic to most of the cells. Surviving colonies were picked and those displaying a high level of IGF-I receptor expression were selected.

[108] CAF1/J female mice, 6 months old, were immunized intraperitoneally on day 0 with Y1251F-mutant-human-IGF-I-receptor-overexpressing cells ($5x10^5$ cells, suspended in 0.2 mL PBS). The animals were boosted with 0.2 mL cell suspension as follows: day 2, $1x10^6$ cells; day 5, $2x10^6$ cells; days 7, 9, 12, and 23, $1x10^7$ cells. On day 26, a mouse was sacrificed and its spleen removed.

[109] The spleen was ground between two frosted glass slides to obtain a single cell suspension, which was washed with serum-free RPMI medium containing penicillin and streptomycin (SFM). The spleen cell pellet was resuspended in 10 mL of 0.83% (w/v) ammonium chloride solution in water for 10 min on ice to lyse the red blood cells, and was then washed with serum-free medium (SFM). Spleen cells ($1.2x10^8$) were pooled with myeloma cells ($4x10^7$) from the non-secreting mouse myeloma cell line P3X63Ag8.653 (ATCC, Rockville, MD; Cat. # CRL1580) in a tube, and washed with the serum-free RPMI-1640 medium (SFM). The supernatant was removed and the cell pellet resuspended in the residual medium. The tube was placed in a beaker of water at 37°C and 1.5 mL of polyethylene glycol solution (50% PEG (w/v), average molecular weight 1500 in 75 mM HEPES, pH 8) was added slowly at a drop rate of 0.5 mL/minute while the tube was gently shaken. After a wait of one minute, 10 mL of SFM was added as follows: 1 mL over the first minute, 2 mL over the second minute, and 7 mL over the third minute. Another 10 mL was then added slowly over one minute. Cells were pelleted by centrifugation, washed in SFM and resuspended in RPMI-1640 growth medium

supplemented with 5% fetal bovine serum (FBS), hypoxanthine/aminopterin/ thymidine (HAT), penicillin, streptomycin, and 10% hybridoma cloning supplement (HCS). Cells were seeded into 96-well flat-bottom tissue culture plates at $2x10^5$ spleen cells in 200 μL per well. After 5-7 days, 100 μL per well were removed and replaced with growth medium supplemented with hypoxanthine/thymidine (HT) and 5% FBS. The general conditions used for immunization and hybridoma production were as described by J. Langone and H. Vunakis (Eds., Methods in Enzymology, Vol. 121, "Immunochemical Techniques, Part I"; 1986; Academic Press, Florida) and E. Harlow and D. Lane ("Antibodies: A Laboratory Manual"; 1988; Cold Spring Harbor Laboratory Press, New York). Other techniques of immunization and hybridoma production can also be used, as are well known to those of skill in the art.

[110] Culture supernatants from hybridoma clones were screened for binding to purified human IGF-I receptor by ELISA, for specific binding to cells overexpressing human IGF-I receptor, and for a lack of binding to cells overexpressing human insulin receptor by ELISA and FACS screening as described below. Clones exhibiting higher binding affinity to cells overexpressing human IGF-I receptor than to cells overexpressing human insulin receptor were expanded and subcloned. The culture supernatants of the subclones were further screened by the above binding assays. By this procedure, subclone 3F1-C8-D7 (EM164) was selected, and the heavy and light chain genes were cloned and sequenced as described below.

[111] Human IGF-I receptor was isolated for use in the screening of supernatants from hybridoma clones for their binding to IGF-I receptor by the method below. Biotinylated IGF-I was prepared by modification of recombinant IGF-I using biotinylating reagents such as sulfo-NHS-LC-biotin, sulfo-NHS-SS-biotin, or NHS-PEO_4-biotin. Biotinylated IGF-I was absorbed

on streptavidin-agarose beads and incubated with lysate from cells that overexpressed human wild type or Y1251F mutant IGFR. The beads were washed and eluted with a buffer containing 2 to 4 M urea and detergent such as triton X-100 or octyl-β-glucoside. Eluted IGF-I receptor was dialyzed against PBS and was analyzed for purity by SDS-PAGE under reducing conditions, which showed alpha and beta chain bands of IGF-I receptor of molecular weights about 135 kDa and 95 kDa, respectively.

[112] To check for the binding of hybridoma supernatants to purified IGF-I receptor, an Immulon-4HB ELISA plate (Dynatech) was coated with a purified human IGF-I receptor sample (prepared by dialysis from urea/octyl-β-glucoside elution of affinity purified sample) diluted in 50 mM CHES buffer at pH 9.5 (100 μL; 4°C, overnight). The wells were blocked with 200 μL of blocking buffer (10 mg/mL BSA in TBS-T buffer containing 50 mM Tris, 150 mM NaCl, pH 7.5, and 0.1% Tween-20) and incubated with supernatants from hybridoma clones (100 μL; diluted in blocking buffer) for about 1 h to 12 h, washed with TBS-T buffer, and incubated with goat-anti-mouse-IgG-Fc-antibody-horseradish peroxidase (HRP) conjugate (100 μL; 0.8 μg/mL in blocking buffer; Jackson ImmunoResearch Laboratories), followed by washes and detection using ABTS/H_2O_2 substrate at 405 nm (0.5 mg/mL ABTS, 0.03% H_2O_2 in 0.1 M citrate buffer, pH 4.2). Typically, a supernatant from a 3F1 hybridoma subclone yielded a signal of about 1.2 absorbance units within 3 min of development, in contrast to values of 0.0 obtained for supernatants from some other hybridoma clones. General conditions for this ELISA were similar to the standard ELISA conditions for antibody binding and detection as described by E. Harlow and D. Lane ("Using Antibodies: A Laboratory Manual"; 1999, Cold Spring Harbor Laboratory Press, New York), which conditions can also be used.

[113] Screening of hybridoma supernatants for specific binding to human IGF-I receptor and not to human insulin receptor was performed using ELISA on cell lines that overexpressed human Y1251F-IGF-I receptor and on cell lines that overexpressed human insulin receptor. Both cell lines were generated from 3T3-like cells of IGF-I receptor deficient mice. The IGF-I receptor overexpressing cells and insulin receptor overexpressing cells were separately harvested from tissue culture flasks by quick trypsin/EDTA treatment, suspended in growth medium containing 10% FBS, pelleted by centrifugation, and washed with PBS. The washed cells (100 μL of about 1-3 x 10^6 cells/mL) were added to wells of an Immulon-2HB plate coated with phytohemagglutinin (100 μL of 20 μg/mL PHA), centrifuged and allowed to adhere to PHA-coated wells for 10 min. The plate with cells was flicked to remove PBS and was then dried overnight at 37°C. The wells were blocked with 5 mg/mL BSA solution in PBS for 1 h at 37°C and were then washed gently with PBS. Aliquots of the supernatants from hybridoma clones (100 μL; diluted in blocking buffer) were then added to wells containing IGF-I-receptor-overexpressing cells and to wells containing insulin receptor-overexpressing cells and were incubated at ambient temperature for 1 h. The wells were washed with PBS, incubated with goat-anti-mouse-IgG-Fc-antibody-horseradish peroxidase conjugate (100 μL; 0.8 μg/mL in blocking buffer) for 1 h, followed by washes and then binding was detected using an ABTS/H_2O_2 substrate. A typical supernatant from a 3F1 hybridoma subclone upon incubation with cells overexpressing IGF-I receptor yielded a signal of 0.88 absorbance units within 12 min of development, in contrast to a value of 0.22 absorbance units obtained upon incubation with cells overexpressing human insulin receptor.

[114] The hybridoma was grown in Integra CL 350 flasks (Integra Biosciences, Maryland), according to manufacturer's specifications, to provide purified EM164 antibody. A yield of about 0.5-1 mg/mL antibody was obtained in the harvested supernatants from the Integra flasks, based on quantitation by ELISA and by SDS-PAGE/Coomassie blue staining using antibody standards. The antibody was purified by affinity chromatography on Protein A-agarose bead column under standard purification conditions of loading and washing in 100 mM Tris buffer, pH 8.9, containing 3 M NaCl, followed by elution in 100 mM acetic acid solution containing 150 mM NaCl. The eluted fractions containing antibody were neutralized with cold 2 M K_2HPO_4 solution and dialyzed in PBS at 4°C. The concentration of the antibody was determined by measuring absorbance at 280 nm (extinction coefficient = 1.4 mg^{-1} mL cm^{-1}). The purified antibody sample was analyzed by SDS-PAGE under reducing conditions and Coomassie blue staining, which indicated only heavy and light chain bands of antibody at about 55 kDa and 25 kDa, respectively. The isotype of the purified antibody was IgG_1 with kappa light chain.

B. **Binding characterization of EM164 Antibody**

[115] The specific binding of the purified EM 164 antibody was demonstrated by fluorescence activated cell sorting (FACS) using cells overexpressing human IGF-I receptor and by using cells that overexpressed human insulin receptor (Figure 1). Incubation of EM 164 antibody (50-100 nM) in 100 μL cold FACS buffer (1 mg/mL BSA in Dulbecco's MEM medium) was performed using cells overexpressing IGF-I receptor and using cells overexpressing insulin receptor ($2x10^5$ cells/mL) in a round-bottom 96-well plate for 1 h. The cells were pelleted by centrifugation and washed with cold FACS buffer by gentle flicking, followed by incubation with goat-anti-mouse-IgG-antibody-FITC conjugate (100 μL; 10 μg/mL in FACS buffer) on ice

for 1 h. The cells were pelleted, washed, and resuspended in 120 μL of 1% formaldehyde solution in PBS. The plate was analyzed using a FACSCalibur reader (BD Biosciences).

[116] A strong fluorescence shift was obtained upon incubation of IGF-I receptor overexpressing cells with EM 164 antibody, in contrast to an insignificant shift upon incubation of insulin receptor overexpressing cells with EM 164 antibody (Figure 1), which demonstrated that the EM 164 antibody was selective in its binding to IGF-I receptor and did not bind to insulin receptor. The control antibodies, anti-IGF-I receptor antibody 1H7 (Santa Cruz Biotechnology) and anti-insulin receptor alpha antibody (BD Pharmingen Laboratories), yielded fluorescence shifts upon incubations with cells that overexpressed IGF-I receptor and insulin receptor, respectively (Figure 1). A strong fluorescence shift was also observed by FACS assay using EM 164 antibody and human breast cancer MCF-7 cells, which expressed IGF-I receptor (Dufourny, B. et al., 1997, *J. Biol. Chem.*, 272, 31163-31171), which showed that EM164 antibody bound to human IGF-I receptor on the surface of human tumor cells.

[117] The dissociation constant (K_d) for the binding of EM164 antibody with human IGF-I receptor was determined by ELISA titration of the binding of antibody at several concentrations with either directly coated IGF-I receptor (affinity purified using biotinylated IGF-I, as above) or indirectly captured biotinylated IGF-I receptor. Biotinylated IGF-I receptor was prepared by biotinylation of detergent-solubilized lysate from IGF-I receptor overexpressing cells using PEO-maleimide-biotin reagent (Pierce, Molecular Biosciences), which was affinity purified using an anti-IGF-I receptor beta chain antibody immobilized on NHS-agarose beads and was eluted with 2-4 M urea in buffer containing NP-40 detergent and dialyzed in PBS.

[118] The K_d determination for the binding of EM164 antibody with biotinylated IGF-I receptor was carried out by coating Immulon-2HB plates with 100 μL of 1 μg/mL streptavidin in carbonate buffer (150 mM sodium carbonate, 350 mM sodium bicarbonate) at 4°C overnight. The streptavidin-coated wells were blocked with 200 μL of blocking buffer (10 mg/mL BSA in TBS-T buffer), washed with TBS-T buffer and incubated with biotinylated IGF-I receptor (10 to 100 ng) for 4 h at ambient temperature. The wells containing indirectly captured biotinylated IGF-I receptor were then washed and incubated with EM164 antibody in blocking buffer at several concentrations (5.1×10^{-13} M to 200 nM) for 2 h at ambient temperature and were then incubated overnight at 4°C. The wells were next washed with TBS-T buffer and incubated with goat-anti-mouse-IgG_{H+L}-antibody-horseradish peroxidase conjugate (100 μL; 0.5 μg/mL in blocking buffer), followed by washes and detection using ABTS/H_2O_2 substrate at 405 nm. The value of K_d was estimated by non-linear regression for one-site binding.

[119] A similar binding titration was carried out using the Fab fragment of EM164 antibody, prepared by papain digestion of the antibody as described by E. Harlow and D. Lane ("Using Antibodies: A Laboratory Manual"; 1999, Cold Spring Harbor Laboratory Press, New York).

[120] The binding titration curve for the binding of EM164 antibody to biotinylated human IGF-I receptor yielded a K_d value of 0.1 nM (Figure 2). The Fab fragment of EM164 antibody also bound the human IGF-I receptor very tightly with a K_d value of 0.3 nM, which indicated that the monomeric binding of the EM164 antibody to IGF-I receptor was also very strong.

[121] This extremely low value of dissociation constant for the binding of IGF-I receptor by EM164 antibody was in part due to a very slow k_{off} rate as verified by the strong binding signals observed after prolonged 1-2 day washes of the antibody bound to immobilized IGF-I receptor.

[122] EM164 antibody can be used for immunoprecipitation of IGF-I receptor, as demonstrated by incubation of detergent-solubilized lysate of the human breast cancer MCF-7 cells with EM164 antibody immobilized on protein G-agarose beads (Pierce Chemical Company). A Western blot of the EM164 antibody immunoprecipitate was detected using a rabbit polyclonal anti-IGF-I receptor beta chain (C-terminus) antibody (Santa Cruz Biotechnology) and a goat-anti-rabbit-IgG-antibody-horseradish peroxidase conjugate, followed by washes and enhanced chemiluminescence (ECL) detection. The Western blot of EM164 immunoprecipitate from MCF-7 cells exhibited bands corresponding to the beta chain of IGF-I receptor at about 95 kDa and the pro-IGF-I receptor at about 220 kDa. Similar immunoprecipitations were carried out for other cell types to check species specificity of the binding of EM164 antibody, which also bound to IGF-I receptor from cos-7 cells (African green monkey), but did not bind to IGF-I receptor of 3T3 cells (mouse), CHO cells (Chinese hamster) or goat fibroblast cells (goat). The EM164 antibody did not detect SDS-denatured human IGF-I receptor in Western blots of lysates from MCF-7 cells, which indicated that it bound to a conformational epitope of native, non-denatured human IGF-I receptor.

[123] The binding domain of EM164 antibody was further characterized using a truncated alpha chain construct, which comprised the cysteine rich domain flanked by L1 and L2 domains (residues 1-468) fused with the 16-mer-C-terminus piece (residues 704-719) and which was terminated by a C-terminus epitope tag. This smaller IGF-I receptor, which lacked residues 469-703, has been reported to bind IGF-I, although less tightly compared to the native full-length IGF-I receptor (Molina, L. et al., 2000, *FEBS Letters*, 467, 226-230; Kristensen, C. et al., 1999, *J. Biol. Chem.*, 274, 37251-37356). Thus, a truncated IGF-I receptor alpha chain construct was prepared comprising residues 1-468 fused to the C-terminus piece that is residues 704-719 and

flanked by a C-terminus myc epitope tag. A stable cell line which expressed this construct, and which also expresses the construct transiently in human embryonic kidney 293T cells, was constructed. A strong binding of EM164 antibody to this truncated IGF-I receptor alpha chain construct was observed. Of the two antibodies tested, IR3 (Calbiochem) also bound to this truncated alpha chain, but 1H7 antibody (Santa Cruz Biotechnology) did not bind, which indicated that the epitope of EM164 antibody was clearly distinct from that of 1H7 antibody.

C. **Inhibition of binding of IGF-I to MCF-7 cells by EM164 antibody**

[124] The binding of IGF-I to human breast cancer MCF-7 cells was inhibited by EM164 antibody (Figure 3). MCF-7 cells were incubated with or without 5 µg/mL EM164 antibody for 2 h in serum-free medium, followed by incubation with 50 ng/mL biotinylated IGF-I for 20 min at 37°C. The cells were then washed twice with serum-free medium to remove unbound biotin-IGF-I, and were then lysed in 50 mM HEPES, pH 7.4, containing 1% NP-40 and protease inhibitors. An Immulon-2HB ELISA plate was coated with a mouse monoclonal anti-IGF-I receptor beta chain antibody and was used to capture the IGF-I receptor and bound biotin-IGF-I from the lysate. The binding of the coated antibody to the cytoplasmic C-terminal domain of the beta chain of IGF-I receptor did not interfere with the binding of biotin-IGF-I to the extracellular domain of IGF-I receptor. The wells were washed, incubated with streptavidin-horseradish peroxidase conjugate, washed again, and then detected using ABTS/H_2O_2 substrate. The inhibition of IGF-I binding to MCF-7 cells by 5 µg/mL EM164 antibody was essentially quantitative, and was almost equivalent to that of the ELISA background obtained using a control lacking biotin-IGF-I.

[125] In addition to the assay described above for the inhibition of binding of IGF-I to MCF-7 cells by EM164 antibody, the following assay demonstrated that EM164 antibody was highly effective at displacing bound IGF-I from MCF-7 cells, as desired under physiological conditions for an antagonistic anti-IGF-I receptor antibody to displace the bound endogenous physiological ligand (such as IGF-I or IGF-II). In this IGF-I displacement assay, MCF-7 cells grown in a 12-well plate were serum-starved and then incubated with biotinylated IGF-I (20-50 ng/mL) in serum-free medium at 37°C (or at 4°C) for 1 to 2 h. The cells with bound biotinylated IGF-I were then treated with EM164 antibody or a control antibody (10-100 μg/mL) at 37°C (or at 4°C) for 30 min to 4 h. Cells were then washed with PBS and lysed in lysis buffer containing 1% NP-40 at 4°C. ELISA was carried out as described above to capture the IGF-I receptor from the lysate and then detect the biotinylated IGF-I bound to the receptor using streptavidin-horseradish peroxidase conjugate. This ELISA demonstrated that EM164 antibody was able to displace pre-bound biotinylated IGF-I from cells nearly completely (90% within 30 min and ~100% within 4 h) at 37°C and by about 50% in 2 h at 4°C. In another experiment, NCI-H838 lung cancer cells were incubated with biotin-IGF-I, then washed and incubated with EM164 antibody at 4°C for 2 h, which resulted in a 80% decrease in the bound biotin-IGF-I. Therefore, EM164 antibody was highly effective at displacing pre-bound IGF-I from cancer cells, which would be important therapeutically for the antagonism of the IGF-I receptor by displacement of the bound endogenous physiological ligand.

[126] The incubation of MCF-7 cells with EM164 antibody at 4°C for 2 h (or at 37°C for 30 min) did not result in a significant downregulation of the IGF-I receptor based on Western blot analysis using anti-IGF-I receptor beta chain antibody (Santa Cruz Biotechnology; sc-713),

although a longer incubation with EM164 antibody at 37°C for 2 h resulted in a 25% downregulation of the IGF-I receptor. Therefore, the inhibition of binding of IGF-I and the displacement of bound IGF-I by EM164 antibody at both 4°C and 37°C in these short-term experiments may not be explained by the down-regulation of the receptor due to the binding of the EM164 antibody. The mechanism for the potent inhibition of the binding of IGF-I to IGF-I receptor and for the displacement of the pre-bound IGF-I by EM164 antibody is likely to be competition for binding, either through sharing of the binding site or through steric occlusion or through allosteric effects.

D. **Inhibition of IGF-I receptor mediated cell signaling by EM164 antibody**

[127] Treatment of breast cancer MCF-7 cells and osteosarcoma SaOS-2 cells with EM164 antibody almost completely inhibited intracellular IGF-I receptor signaling, as shown by the inhibition of IGF-I receptor autophosphorylation and by the inhibition of phosphorylation of its downstream effectors such as insulin receptor substrate-1 (IRS-1), Akt and Erk1/2 (Figures 4-6).

[128] In Figure 4, the MCF-7 cells were grown in a 12-well plate in regular medium for 3 days, and were then treated with 20 μg/mL EM164 antibody (or anti-B4 control antibody) in serum-free medium for 3 h, followed by stimulation with 50 ng/mL IGF-I for 20 min at 37°C. The cells were then lysed in ice-cold lysis buffer containing protease and phosphatase inhibitors (50 mM HEPES buffer, pH 7.4, 1% NP-40, 1 mM sodium orthovanadate, 100 mM sodium fluoride, 10 mM sodium pyrophosphate, 2.5 mM EDTA, 10 μM leupeptin, 5 μM pepstatin, 1 mM PMSF, 5 mM benzamidine, and 5 μg/mL aprotinin). An ELISA plate was pre-coated with anti-IGF-I receptor beta chain C-terminus monoclonal antibody TC123 and was incubated with the lysate samples for 5 h at ambient temperature to capture IGF-I receptor. The wells containing the

captured IGF-I receptor were then washed and incubated with biotinylated anti-phosphotyrosine antibody (PY20; 0.25 μg/mL; BD Transduction Laboratories) for 30 min, followed by washes and incubation with streptavidin-horseradish peroxidase conjugate (0.8 μg/mL) for 30 min. The wells were washed and detected with ABTS/H_2O_2 substrate. Use of a control anti-B4 antibody showed no inhibition of the IGF-I stimulated autophosphorylation of IGF-I receptor. In contrast, a complete inhibition of the IGF-I stimulated autophosphorylation of IGF-I receptor was obtained upon treatment with EM164 antibody (Figure 4).

[129] To demonstrate inhibition of phosphorylation of insulin receptor substrate-1 (IRS-1), an ELISA using immobilized anti-IRS-1 antibody to capture IRS-1 from lysates was used, followed by measurement of the associated p85 subunit of phosphatidylinositol-3-kinase (PI-3-kinase) that binds to the phosphorylated IRS-1 (Jackson, J. G. et al., 1998, *J. Biol. Chem.*, 273, 9994-10003). In Figure 5, MCF-7 cells were treated with 5 μg/mL antibody (EM164 or IR3) in serum-free medium for 2 h, followed by stimulation with 50 ng/mL IGF-I for 10 min at 37°C. Anti-IRS-1 antibody (rabbit polyclonal; Upstate Biotechnology) was indirectly captured by incubation with coated goat-anti-rabbit-IgG antibody on an ELISA plate, which was then used to capture IRS-1 from the cell lysate samples by overnight incubation at 4°C. The wells were then incubated with mouse monoclonal anti-p85-PI-3-kinase antibody (Upstate Biotechnology) for 4 h, followed by treatment with goat-anti-mouse-IgG-antibody-HRP conjugate for 30 min. The wells were then washed and detected using ABTS/ H_2O_2 substrate (Figure 5). As shown in Figure 5, EM164 antibody was more effective at inhibiting the IGF-I-stimulated IRS-1 phosphorylation than was IR3 antibody, and EM164 antibody did not show any agonistic activity on IRS-1 phosphorylation when incubated with cells in the absence of IGF-I.

[130] The activation of other downstream effectors, such as Akt and Erk1/2, was also inhibited in a dose-dependent manner by EM164 antibody in SaOS-2 cells (Figure 6) and in MCF-7 cells, as was shown using Western blots of lysates and phosphorylation-specific antibodies (rabbit polyclonal anti-phospho-Ser^{473} Akt polyclonal and anti-phospho-ERK1/2 antibodies; Cell Signaling Technology). A pan-ERK antibody demonstrated equal protein loads in all lanes (Figure 6). Treatment of SaOS-2 cells with EM164 antibody did not inhibit the EGF-stimulated phosphorylation of Erk1/2, thus demonstrating the specificity of inhibition of IGF-I receptor signaling pathway by EM164 antibody.

E. **Inhibition of IGF-I-, IGF-II- and serum-stimulated growth and survival of human tumor cells by EM164 antibody**

[131] Several human tumor cell lines were tested in serum-free conditions for their growth and survival response to IGF-I. These cell lines were treated with EM164 antibody in the presence of IGF-I, IGF-II, or serum, and their growth and survival responses were measured using an MTT assay after 2-4 days. Approximately 1500 cells were plated in a 96-well plate in regular medium with serum, which was replaced with serum-free medium the following day (either serum-free RPMI medium supplemented with transferrin and BSA, or phenol-red free medium as specified by Dufourny, B. et al., 1997, *J. Biol. Chem.*, 272, 31163-31171). After one day of growth in serum-free medium, the cells were incubated with about 75 μL of 10 μg/mL antibody for 30 min.-3 h, followed by the addition of 25 μL of IGF-I (or IGF-II or serum) solution to obtain a final concentration of 10 ng/mL IGF-I, or 20 ng/mL IGF-II, or 0.04-10% serum. In some experiments, the cells were stimulated first with IGF-I for 15 min before the addition of EM164 antibody, or both IGF-I and EM164 antibody were added together. The cells were then allowed to grow for another 2-3 days. A solution of MTT (3-(4,5)-dimethylthiazol-2-yl)-2,5-

diphenyltetrazolium bromide; 25 μL of a 5 mg/mL solution in PBS) was then added and the cells were returned to the incubator for 2-3 h. The medium was then removed and replaced by 100 μL DMSO, mixed, and the absorbance of the plate was measured at 545 nm. Several human tumor cell lines showed a growth and survival response upon addition of IGF-I or IGF-II or serum that was significantly inhibited by EM164 antibody, irrespective of whether the antibody was added before IGF-I, or if IGF-I was added before the antibody, or if both IGF-I and antibody were added together (Table 1).

TABLE 1. Inhibition of IGF-I-stimulated growth and survival of tumor cells by EM164 antibody

Tumor Cell Type	Fold growth response to IGF-I (MTT assay: ratio for IGF-I treated *vs* untreated cells in serum-free medium)[a]	% Inhibition by EM164 antibody of IGF-I-stimulated growth in serum-free medium	Inhibition by EM164 antibody of Growth/survival of cells in 1.25-10 % serum[b]
MCF-7 (breast)	1.7-2.8	100 %	85 %
HT-3 (cervical)	2	70-90 %	ND
Colo 205 (colon)	2.3	50 %	Yes
HT-29	1.5	60 %	Yes
NCI-H838 (lung)	3	100 %	85-90 %
Calu-6	1.6-1.8	85 %	Yes
SK-LU-1	1.4	100%	No
NCI-H596	1.4	100 %	Weakly
A 549	1.2	80 %	ND
A 375 (melanoma)	1.6	90 %	No
SK-Mel-37	1.4	85 %	ND
RD (rhabdomyocarcoma)	1.7	85-100 %	Yes
SaOS-2 (osteosarcoma)	2.5	100 %	Yes
A 431 (epidermoid)	2.2	85 %	Yes
SK-N-SH (neuroblastoma)	2	85 %	30-50 %

[a] MTT assay of 3- to 4-day growth/survival of cells in response to 10 ng/mL IGF-I in serum-free medium containing 5-10 μg/mL EM164 antibody.

[b] Inhibition of growth of cells in 1.25-10 % serum in the presence of 5-10 μg/mL EM164 antibody by MTT assay or colony formation assay based on comparison with the control (with serum but without antibody); the extent of inhibition was quantitatively measured for MCF-7, NCI-H838 and SK-N-SH cells based on controls (without serum but with antibody, and with serum but without antibody) to account for autocrine/paracrine IGF-stimulation by cells. ND indicates no data or poor data due to staining difficulties.

[132] The EM164 antibody strongly inhibited IGF-I-or serum-stimulated growth and survival of breast cancer MCF-7 cells (Figures 7 and 8). In a separate experiment, the EM164 antibody strongly inhibited IGF-II-stimulated growth and survival of MCF-7 cells. Previous reports using commercially available antibodies such as IR3 antibody showed only weak inhibition of serum-stimulated growth and survival of MCF-7 cells, as confirmed in Figure 7 for the IR3 and 1H7 antibodies (Cullen, K. J. et al., 1990, *Cancer Res.*, 50, 48-53). In contrast, EM164 antibody was a potent inhibitor of the serum- or IGF-stimulated growth of MCF-7 cells. As shown in Figure 8, EM164 antibody was equally effective in inhibiting the growth and survival of MCF-7 cells over a wide range of serum concentrations (0.04-10% serum).

[133] The growth inhibition of MCF-7 cells by EM164 antibody was measured by counting cells. Thus, in a 12-well plate, about 7500 cells were plated in RPMI medium with 10% FBS, in the presence or absence of 10 μg/mL EM164 antibody. After 5 days of growth, the cell count for the untreated control sample was 20.5×10^4 cells, in contrast to a cell count of only 1.7×10^4 cells for the EM164 antibody-treated sample. Treatment with the EM164 antibody inhibited the growth of MCF-7 cells by about 12-fold in 5 days. This inhibition by EM164 antibody was significantly greater than was a reported 2.5-fold inhibition using IR3 antibody in a 6-day assay for MCF-7 cells (Rohlik, Q. T. et al., 1987, *Biochem. Biophys. Res. Commun.*, 149, 276-281).

[134] The IGF-I- and serum-stimulated growth and survival of a non-small cell lung cancer line NCI-H838 were also strongly inhibited by EM164 antibody, compared to a control anti-B4 antibody (Figure 9). Treatment with EM164 antibody in serum-free medium produced a smaller signal than the untreated sample for both NCI-H838 and MCF-7 cells, presumably because EM 164 antibody also inhibited the autocrine and paracrine IGF-I and IGF-II stimulation of these

cells (Figures 7 and 9). The colony size of HT29 colon cancer cells was also greatly reduced upon treatment with EM164 antibody.

[135] EM164 antibody is therefore unique among all known anti-IGF-I receptor antibodies in its effectiveness to inhibit the serum-stimulated growth of tumor cells such as MCF-7 cells and NCI-H838 cells by greater than 80%.

[136] The EM164 antibody caused growth arrest of cells in G0/G1 phase of cell cycle and abrogated the mitogenic effect of IGF-I. For cell cycle analysis, MCF-7 cells were treated with IGF-I (20 ng/mL) in the presence or absence of EM164 (20 μg/mL) for 1 day and then analyzed by propidium iodide staining and flow cytometry. As shown in Figure 25, the cycling of cells in response to IGF-I stimulation in the absence of EM164 (with 41% of the cells in the S phase and 50% in the G0/G1 phase) was suppressed in EM164-treated cells (with only 9% in the S phase and 77% of the cells in the G0/G1 phase).

[137] In addition to its inhibition of cell proliferation, EM164 antibody treatment resulted in apoptosis of cells. For measurement of apoptosis, cleavage of the cytokeratin CK18 protein by caspase was measured in NCI-H838 lung cancer cells incubated with IGF-I or serum in the presence or absence of EM164 for 1 day (Figure 26). In the absence of EM164, the addition of IGF-I or serum resulted in a lower caspase-cleaved CK18 signal compared to the no IGF-I control, indicating that IGF-I and serum prevent the activation of caspase. Treatment with EM164 suppressed the anti-apoptotic effects of IGF-I and serum, as indicated by the greater cleaved CK18 levels obtained in the presence of EM164 than in the absence of EM164 (Figure 26).

F. **Synergistic inhibition by EM164 antibody of growth and survival of human tumor cells in combinations with other cytotoxic and cytostatic agents**

[138] The combined administration of EM164 antibody with taxol was significantly more inhibitory to the growth and survival of non-small cell lung cancer Calu6 cells than was taxol alone. Similarly, the combination of EM164 antibody with camptothecin was significantly more inhibitory than camptothecin alone toward the growth and survival of colon cancer HT29 cells. Because EM164 antibody alone was not expected to be as toxic to cells as organic chemotoxic drugs, the synergism between the predominantly cytostatic effect of EM164 antibody and the cytotoxic effect of the chemotoxic drug may be highly efficacious in combination cancer therapies in clinical settings.

[139] The combined effect of EM164 antibody with an anti-EGF receptor antibody (KS77) was significantly more inhibitory than either EM164 antibody or KS77 antibody alone on the growth and survival of several tumor cell lines such as HT-3 cells, RD cells, MCF-7 cells, and A431 cells. Therefore, the synergistic effect of combining neutralizing antibodies for two growth factor receptors such as IGF-I receptor and EGF receptor may also be useful in clinical cancer treatment.

[140] Based on the efficacy of EM164 antibody as a single agent in inhibiting the proliferation and survival of diverse human cancer cell lines as shown in Table 1, additional efficacy studies were carried out using combinations of EM164 antibody with other anti-cancer therapeutic agents. In these studies on diverse cancer cell lines, the combined treatment of EM164 antibody and other anti-cancer therapeutic agents resulted in an even greater anti-cancer efficacy than with either EM164 or the other therapeutic agent alone. These combinations of EM164 with other therapeutic agents are therefore highly effective in inhibiting the proliferation and survival of

cancer cells. The therapeutic agents that can be combined with EM164 for improved anti-cancer efficacy include diverse agents used in oncology practice (*Reference*: Cancer, Principles & Practice of Oncology, DeVita, V. T., Hellman, S., Rosenberg, S. A., 6th edition, Lippincott-Raven, Philadelphia, 2001), such as docetaxel, paclitaxel, doxorubicin, epirubicin, cyclophosphamide, trastuzumab (Herceptin), capecitabine, tamoxifen, toremifene, letrozole, anastrozole, fulvestrant, exemestane, goserelin, oxaliplatin, carboplatin, cisplatin, dexamethasone, antide, bevacizumab (Avastin), 5-fluorouracil, leucovorin, levamisole, irinotecan, etoposide, topotecan, gemcitabine, vinorelbine, estramustine, mitoxantrone, abarelix, zoledronate, streptozocin, rituximab (Rituxan), idarubicin, busulfan, chlorambucil, fludarabine, imatinib, cytarabine, ibritumomab (Zevalin), tositumomab (Bexxar), interferon alpha-2b, melphalam, bortezomib (Velcade), altretamine, asparaginase, gefitinib (Iressa), erlonitib (Tarceva), anti-EGF receptor antibody (Cetuximab, Abx-EGF), epothilones, and conjugates of cytotoxic drugs and antibodies against cell-surface receptors.

[141] For these combination therapies, EM164 is combined with one or more anti-cancer agents of diverse mechanisms of action such as alkylating agents, platinum agents, hormonal therapies, antimetabolites, topoisomerase inhibitors, antimicrotubule agents, differentiation agents, antiangiogenic or antivascularization therapies, radiation therapy, agonists and antagonists of leuteinizing hormone releasing hormone (LHRH) or gonadotropin-releasing hormone (GnRH), inhibitory antibodies or small molecule inhibitors against cell-surface receptors, and other chemotherapeutic agents (*Reference*: Cancer, Principles & Practice of Oncology, DeVita, V. T., Hellman, S., Rosenberg, S. A., 6th edition, Lippincott-Raven, Philadelphia, 2001). In one example, the combination of an LHRH antagonist antide (0.1 to 10 micromolar) and EM164 antibody (0.1 to 10 nanomolar) inhibited the proliferation of MCF-7

breast cancer cells significantly more than that with either EM164 or antide alone. In an example of a combination therapy with a platinum agent, the combined treatment with EM164 antibody (10 microgram/ml) and cisplatin (0.1-60 microgram/ml) resulted in a greater inhibition of the proliferation and survival of MCF-7 breast cancer cells in comparison to the inhibition by either EM164 antibody or cisplatin alone.

[142] These combinations of EM164 antibody with other therapeutic agents are effective against several types of cancers including breast, lung, colon, prostate, pancreatic, cervical, ovarian, melanoma, multiple myeloma, neuroblastoma, rhabdomyosarcoma and osteosarcoma. The EM164 antibody and the therapeutic agent can be administered for cancer therapy either simultaneously or in sequence.

[143] Conjugates of EM164 antibody with cytotoxic drugs are also valuable in targeted delivery of the cytotoxic drugs to the tumors overexpressing IGF-I receptor. Conjugates of EM164 antibody with radiolabels or other labels can be used in the treatment and imaging of tumors that overexpress IGF-I receptor.

G. **Effect of EM164 treatment, as a single agent or in combination with anti-cancer agents, in human cancer xenografts in immunodeficient mice**

[144] Human non-small cell lung cancer Calu-6 xenografts were established in immunodeficient mice by subcutaneous injections of 1×10^7 Calu-6 cells. As shown in Figure 10, these mice containing established 100 mm^3 Calu-6 xenografts were treated with EM 164 antibody alone (6 injections of 0.8 mg/mouse, i. v., two per week) or with taxol alone (five injections of taxol, i.p. every two days; 15 mg/kg), or with a combination of taxol and EM164 antibody treatments, or PBS alone (200 μL/mouse, 6 injections, two per week, i.v.) using five mice per treatment group. The growth of tumors was significantly slowed by EM164 antibody

treatment compared to a PBS control. No toxicity of EM164 antibody was observed, based on measurements of the weights of the mice. Although taxol treatment alone was effective until day 14, the tumor then started to grow back. However, the growth of the tumor was delayed significantly in the group that was treated by a combination of taxol and EM164 antibody, compared to the group that was treated with taxol alone.

[145] Human pancreatic cancer xenografts were established in 5 week-old, female SCID/ICR mice (Taconic) by subcutaneous injections of 10^7 BxPC-3 cells in PBS (day 0). The mice bearing established tumors of 80 mm^3 were then treated with EM164 alone (13 injections of 0.8 mg/mouse, i.v., lateral tail vein, on days 12, 16, 19, 23, 26, 29, 36, 43, 50, 54, 58, 61 and 64), with gemcitabine alone (two injections of 150 mg/kg/mouse, i.p., on days 12 and 19), with a combination of gemcitabine and EM164 following the above schedules, PBS alone, and a control antibody alone (following the same schedule as EM164) using five mice in each of the five treatment groups. As shown in Figure 27, treatment with EM164 alone, or in combination with gemcitabine, resulted initially in total regression of tumor xenografts in 4 of 5 animals in the EM164 treatment group and in all 5 animals in the combination treatment group. Measurable tumor regrowth was only seen in more than one animal on day 43 in the EM164 group and on day 68 in the combination treatment group, resulting in significantly smaller mean tumor volumes on day 74 in comparison with the control treatments (P = 0.029 and 0.002, respectively; two-tailed *T*-test; Figure 27). In another study, EM164 antibody treatment (alone or in combination with an anti-EGF receptor antibody; intraperitoneal injections) inhibited the growth of established BxPC-3 xenografts in mice.

[146] The murine EM164 and the humanized EM164 antibodies showed equivalent inhibition of the growth of established BxPC-3 xenografts in mice, thus demonstrating that the potency of

the humanized EM164 is equivalent to that of the murine EM164 *in vivo*. In a comparison of different modes of administration of EM164 antibody, both intraperitoneal and intravenous administrations of EM164 antibody showed equivalent inhibition of the growth of established BxPC-3 xenografts in mice. In another xenograft study, treatment with EM164 antibody showed significant growth delay of established A-673 human rhabdomyosarcoma/Ewing's sarcoma xenografts in mice.

H. **Cloning and sequencing of the light and heavy chains of EM164 antibody**

[147] Total RNA was purified from EM164 hybridoma cells. Reverse transcriptase reactions were performed using 4-5 μg total RNA and either oligo dT or random hexamer primers.

[148] PCR reactions were performed using a RACE method described in Co et al. (J. Immunol., 148, 1149-1154 (1992)) and using degenerate primers as described in Wang et al., (J. Immunol. Methods, 233, 167-177 (2000)). The RACE PCR method required an intermediate step to add a poly G tail on the 3' ends of the first strand cDNAs. RT reactions were purified with Qianeasy (Qiagen) columns and eluted in 50 μl 1 X NEB buffer 4. A dG tailing reaction was performed on the eluate with 0.25 mM $CoCl_2$, 1 mM dGTP, and 5 units terminal transferase (NEB), in 1 X NEB buffer 4. The mixture was incubated at 37°C for 30 minutes and then 1/5 of the reaction (10 μl) was added directly to a PCR reaction to serve as the template DNA.

[149] The RACE and degenerate PCR reactions were identical except for differences in primers and template. The terminal transferase reaction was used directly for the RACE PCR template, while the RT reaction mix was used directly for degenerate PCR reactions.

[150] In both RACE and degenerate PCR reactions the same 3' light chain primer:

HindKL - tatagagctcaagcttggatggtgggaagatggatacagttggtgc (SEQ ID NO: 14)

and 3' heavy chain primer:

Bgl2IgG1 - ggaagatctatagacagatgggggtgtcgttttggc (SEQ ID NO: 15)

were used.

[151] In the RACE PCR, one poly C 5' primer was used for both the heavy and light chain:

EcoPolyC - TATATCTAGAATTCCCCCCCCCCCCCCCCC (SEQ ID NO: 16),

while the degenerate 5' end PCR primers were:

Sac1MK - GGGAGCTCGAYATTGTGMTSACMCARWCTMCA (SEQ ID NO: 17) for the light chain, and an equal mix of:

EcoR1MH1 - CTTCCGGAATTCSARGTNMAGCTGSAGSAGTC (SEQ ID NO: 18) and

EcoR1MH2 - CTTCCGGAATTCSARGTNMAGCTGSAGSAGTCWGG (SEQ ID NO: 19) for the heavy chain.

[152] In the above primer sequences, mixed bases are defined as follows: H=A+T+C, S=g+C, Y=C+T, K= G+T, M=A+C, R=A+g, W=A+T, V = A+C+G.

[153] The PCR reactions were performed using the following program: 1) 94 °C 3 min, 2) 94 °C 15 sec, 3) 45 °C 1 min, 4) 72 °C 2 min, 5) cycle back to step #2 29 times, 6) finish with a final extension step at 72 °C for 10 min.

[154] The PCR products were cloned into pBluescript II SK+ (Stratagene) using restriction enzymes created by the PCR primers.

[155] Several individual light and heavy chain clones were sequenced by conventional means to identify and avoid possible polymerase generated sequence errors (Figures 12 and 13). Using

Chothia canonical classification definitions, the three light chain and heavy chain CDRs were identified (Figures 12-14).

[156] A search of the NCBI IgBlast database indicated that the anti-IGF-I receptor antibody light chain variable region probably derived from the mouse IgVk Cr1 germline gene while the heavy chain variable region probably derived from the IgVh J558.c germline gene (Figure 15).

[157] Protein sequencing of murine EM164 antibody was performed to confirm the sequences shown in Figures 12 and 13. The heavy and light chain protein bands of purified EM164 antibody were transferred to a PVDF membrane from a gel (SDS-PAGE, reducing conditions), excised from the PVDF membrane and analyzed by protein sequencing. The N-terminal sequence of the light chain was determined by Edman sequencing to be: DVLMTQTPLS (SEQ ID NO:20), which matches the N-terminal sequence of the cloned light chain gene obtained from the EM164 hybridoma.

[158] The N-terminus of the heavy chain was found to be blocked for Edman protein sequencing. A tryptic digest peptide fragment of the heavy chain of mass 1129.5 (M+H+, monoisotopic) was fragmented via post-source decay (PSD) and its sequence was determined to be GRPDYYGSSK (SEQ ID NO:21). Another tryptic digest peptide fragment of the heavy chain of mass 2664.2 (M+H+, monoisotopic) was also fragmented via post-source decay (PSD) and its sequence was identified as: SSSTAYMQLSSLTSEDSAVYYFAR (SEQ ID NO:22). Both of these sequences match perfectly those of CDR3 and framework 3 (FR3) of the cloned heavy chain gene obtained from the EM164 hybridoma.

I. **Recombinant expression of EM164 antibody**

[159] The light and heavy chain paired sequences were cloned into a single mammalian expression vector (Figure 16). The PCR primers for the human variable sequences created

restriction sites that allowed the human signal sequence to be attached while in the pBluescriptII cloning vector, and the variable sequences were cloned into the mammalian expression plasmid using EcoRI and BsiWI or HindIII and ApaI sites for the light chain or heavy chain, respectively (Figure 16). The light chain variable sequences were cloned in-frame onto the human IgK constant region and the heavy chain variable sequences were cloned into the human Iggamma1 constant region sequence. In the final expression plasmids, human CMV promoters drove the expression of both the light and heavy chain cDNA sequences. Expression and purification of the recombinant mouse EM164 antibody proceeded according to methods that are well-known in the art.

EXAMPLE 2: Humanized versions of EM164 antibody

[160] Resurfacing of the EM164 antibody to provide humanized versions suitable as therapeutic or diagnostic agents generally proceeds according to the principles and methods disclosed in U.S. Patent 5,639,641, and as follows.

A. Surface prediction

[161] The solvent accessibility of the variable region residues for a set of antibodies with solved structures was used to predict the surface residues for the murine anti-IGF-I receptor antibody (EM164) variable region. The amino acid solvent accessibility for a set of 127 unique antibody structure files (Table 2) were calculated with the MC software package (Pedersen et al., 1994, J. Mol. Biol., 235, 959-973). The ten most similar light chain and heavy chain amino acid sequences from this set of 127 structures were determined by sequence alignment. The average solvent accessibility for each variable region residue was calculated, and positions with greater than a 30% average accessibility were considered to be surface residues. Positions with average

accessibilities of between 25% and 35% were further examined by calculating the individual residue accessibility for only those structures with two identical flanking residues.

TABLE 2 - 127 antibody structures from the Brookhaven database used to predict the surface of anti-IGF-I-receptor antibody (EM164)

127 Brookhaven structure files used for surface predictions									
2rcs	3hfl	3hfm	1aif	1a3r	1bbj	43c9	4fab	6fab	7fab
2gfb	2h1p	2hfl	1a6t	1axt	1bog	2hrp	2jel	2mcp	2pcp
1yuh	2bfv	2cgr	8fab	1ae6	1bvl	2dbl	2f19	2fb4	2fbj
1sm3	1tet	1vfa	glb2	1a4j	1cly	1vge	1yec	1yed	1yee
1nsn	1opg	1osp	1aj7	1ay1	1clz	1plg	1psk	1rmf	1sbs
1ncd	1nfd	1ngp	1acy	1afv	1cbv	1nld	1nma	1nmb	1nqb
1mcp	1mfb	1mim	15c8	1a5f	1axs	1mlb	1mpa	1nbv	1ncb
1jrh	1kb5	1kel	1ap2	1b2w	1adq	1kip	1kir	1lve	1mam
1igi	1igm	1igt	1ad0	1baf	1cfv	1igy	1ikf	1jel	1jhl
1gpo	1hil	1hyx	1a0q	1bjm	1clo	1iai	1ibg	1igc	1igf
1fpt	1frg	1fvc	1aqk	1bln	1d5b	1gaf	1ggi	1ghf	1gig
1fai	1fbi	1fdl	1ad9	1bbd	1f58	1fgv	1fig	1flr	1for
	1dbl	1dfb	1a3l	1bfo	1eap	1dsf	1dvf		

B. **Molecular modeling:**

[162] A molecular model of murine EM164 was generated using the Oxford Molecular software package AbM. The antibody framework was built from structure files for the antibodies with the most similar amino acid sequences, which were 2jel for the light chain and 1nqb for the heavy chain. The non-canonical CDRs were built by searching a C-a structure

database containing non-redundant solved structures. Residues that lie within 5 ? of a CDR were determined.

C. **Human Ab selection**

[163] The surface positions of murine EM164 were compared to the corresponding positions in human antibody sequences in the Kabat database (Johnson, G. and Wu, T. T. (2001) Nucleic Acids Research, 29: 205-206). The antibody database management software SR (Searle 1998) was used to extract and align the antibody surface residues from natural heavy and light chain human antibody pairs. The human antibody surface with the most identical surface residues, with special consideration given to positions that come within 5 ? of a CDR, was chosen to replace the murine anti-IGF-I receptor antibody surface residues.

D. **PCR mutagenesis**

[164] PCR mutagenesis was performed on the murine EM164 cDNA clone (above) to build the resurfaced, human EM164 (herein huEM164). Primer sets were designed to make the 8 amino acid changes required for all tested versions of huEM164, and additional primers were designed to alternatively make the two 5 ? residue changes (Table 3). PCR reactions were performed with the following program: 1) 94 °C 1 min, 2) 94 °C 15 sec, 3) 55 °C 1 min, 4) 72 °C 1 min, 5) cycle back to step #2 29 times, 6) finish with a final extension step at 72 °C for 4 min. The PCR products were digested with their corresponding restriction enzymes and were cloned into the pBluescript cloning vectors as described above. Clones were sequenced to confirm the desired amino acid changes.

TABLE 3 - PCR primers used to build 4 humanized EM164 antibodies

Primer	Sequence	SEQ ID NO:
Em164hcvv	CAGGTGTACACTCCCAGGTCCAACTGGTGCAGTCTGGGG CTGAAGTGGTGAAGCCTG	23
Em164hcqqgol1	CAATCAGAAGTTCCAGGGGAAGGCCACAC	24
Em164hcqqgol2	CCTTCCCCTGGAACTTCTGATTGTAGTTAGTACG	25
Em164lcv3	CAGGTGTACACTCCGATGTTGTGATGACCCAAACTCC	26
Em164lcl3	CAGGTGTACACTCCGATGTTTTGATGACCCAAACTCC	27
Em164lcp18	GACTAGATCTGCAAGAGATGGAGGCTGGATCTCCAAGAC	28
Em164lcbgl2	TTGCAGATCTAGTCAGAGCATAGTACATAGTAATG	29
Em164r45	GAATGGTACCTGCAGAAACCAGGCCAGTCTCCAAGGCTC CTGATCTAC	30
Em164a67ol1	GTGGCAGTGGAGCAGGGACAGATTTCAC	31
Em164a67ol2	GAAATCTGTCCCTGCTCCACTGCCACTG	32

E. **Variable region surface residues**

[165] The antibody resurfacing techniques described by Pedersen et al. (J. Mol. Biol., 235, 959-973, 1994) and Roguska et al. (Protein Eng., 9, 895-904, 1996) begin by predicting the surface residues of the murine antibody variable sequences. A surface residue is defined as an amino acid that has at least 30% of its total surface area accessible to a water molecule.

[166] The 10 most homologous antibodies in the set of 127 antibody structure files were identified (Figures 17 and 18). The solvent accessibility for each Kabat position was averaged for these aligned sequences and the distribution of the relative accessibilities for each residue were as shown in Figure 19. Both the light and heavy chain have 26 residues with average relative accessibilities of at least 30% (Figure 19): these residues were therefore the predicted surface residues for EM164. Several residues had average accessibilities of between 25% and 35%, and these were further examined by averaging only the antibodies with two identical residues flanking either side of the residue (Tables 4 and 5). After this additional analysis, the original set of surface residues that was identified above remained unchanged.

TABLE 4 - Surface residues and average accessibility (ave. acc.) for the l ight and heavy chain variable sequences of EM164 antibody

EM164 Surface Residues					
Light Chain			Heavy Chain		
EM164	Kabat #	Ave. Acc.	EM164	Kabat #	Ave. Acc.
D	1	45.89	Q	1	58.19
L	3	41.53	Q	3	34.08
T	7	31.40	Q	5	34.36
L	9	50.08	A	9	38.01
L	15	35.45	L	11	47.72
Q	18	39.79	K	13	46.51
R	24	34.36	P	14	31.49
S	26	32.63	G	15	31.42
Q	27	34.35	K	19	34.41
N	28	36.38	K	23	31.23
P	40	43.05	T	28	36.24
G	41	46.56	P	41	44.01
Q	42	34.92	G	42	42.62
K	45	30.58	Q	43	46.85
S	52	30.40	E	61	46.68
S	56	41.46	K	62	44.87
G	57	42.41	K	64	38.92
D	60	45.96	R	65	40.06
S	67	38.20	K	73	35.92
R	77	42.61	S	74	48.91
E	81	38.46	S	82B	32.72
V	95E	34.83	S	84	35.21
K	103	31.10	E	85	39.62
K	107	36.94	D	98	36.00
R	108	60.13	A	106	37.65
A	109	53.65	S	113	43.42

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TABLE 5

Borderline Surface Residues					
Light Chain			Heavy Chain		
EM164	Kabat #	Ave. Acc.	EM164	Kabat #	Ave. Acc.
T	5	28.68	Q	3	31.62
T	7	30.24	Q	5	36.07
P	12	26.59	P	14	29.88
G	16	25.20	G	15	30.87
D	17	25.73	S	17	25.64
S	20	25.37	K	19	35.06
R	24	36.73	K	23	31.48
S	26	31.00	G	26	30.53
Q	27	32.29	S	31	27.12
S	27A	29.78	R	56	NA
V	27C	29.05	T	68	27.71
V	29	NA	T	70	24.65
Q	42	34.92	S	75	18.80
K	45	32.24	S	82B	32.87
S	52	30.02	P	97	NA
R	54	29.50	Y	99	NA
D	70	26.03	V	103	NA
R	74	NA	T	111	25.95
E	79	26.64			
A	80	29.61			
V	95E	42.12			
G	100	29.82			
K	103	31.10			
E	105	25.78			

Residues which had average accessibilities between 25% and 35% were further analyzed by averaging a subset of antibodies that had two identical residues flanking either side of the residue in question. These borderline surface positions and their new average accessibilities are given. The NA's refer to residues with no identical flanking residues in the 10 most similar antibodies.

F. **Molecular modeling to determine which residues fall within 5? of a CDR**

[167] The molecular model above, generated with the AbM software package, was analyzed to determine which EM164 surface residues were within 5? of a CDR. In order to resurface the murine EM164 antibody, all surface residues outside of a CDR should be changed to the human counterpart, but residues within 5? of a CDR are treated with special care because they may also contribute to antigen specificity. Therefore, these latter residues must be identified and carefully considered throughout the humanization process. The CDR definitions used for resurfacing combine the AbM definition for heavy chain CDR2 and Kabat definitions for the remaining 5 CDRs (Figure 14). Table 6 shows the residues that were within 5? of any CDR residue in either the light or heavy chain sequence of the EM164 model.

TABLE 6 EM164 antibody framework surface residues within 5? of a CDR

EM164 Surface Residues within 5Å of a CDR

Light chain	Heavy chain
D1	T28
L3	K73
T7	S74
P40	
Q42	
K45	
G57	
D60	
E81	

G. **Identification of the most homologous human surfaces**

[168] Candidate human antibody surfaces for resurfacing EM164 were identified within the Kabat antibody sequence database using SR software, which provided for the searching of only

specified residue positions against the antibody database. To preserve the natural pairings, surface residues of both the light and heavy chains were compared together. The most homologous human surfaces from the Kabat database were aligned in rank order of sequence identity. The top 5 surfaces are given in Table 7. These surfaces were then compared to identify which of them would require the least changes within 5? of a CDR. The Leukemic B-cell antibody, CLL 1.69, required the least number of surface residue changes (10 in total) and only two of these residues were within 5? of a CDR.

[169] The full length variable region sequence for EM164 was also aligned against the Kabat human antibody database and CLL 1.69 was again identified as the most similar human variable region sequence. Together, these sequence comparisons identified the human Leukemic B-cell antibody CLL 1.69 as the preferred choice as a human surface for EM164.

TABLE 7 - The top 5 human sequences extracted from the Kabat database

5 Most Homologous Human Antibody Surfaces		
Antibody	Light Chain	SEQ ID NO:
MuEM164	D L T L L Q P G Q K G D S R E K K R A	33
CLL1.69	D V T L L P P G Q R G D A R E K K R -	34
MSL5	D Q S L I P P G Q K G D S R D K K R A	35
CDP571	D M S S V R P G Q K G S S S D K K R -	36
LC3aPB	E V S G P R P G Q R G D S R E K K R -	37
SSbPB	E V S G P R P G Q R G D S R E K K R -	38
Antibody	Heavy Chain	SEQ ID NO:
MuEM164	Q Q Q A L K P G K K T P G Q E K K R K S S S E A S	39
CLL1.69	Q Q V A V K P G K K T P G Q Q K Q G K S S S E Q S	40
MSL5	Q Q Q P L K P G K K T P G K D D K G T S N N E Q S	41
CDP571	Q Q V A V K P G K K T P G Q Q K K G K S S S E Q S	42
LC3aPB	- Q V A V K P G K K T P G Q Q K Q G K S S S E Q S	43
SSbPB	- Q V A V K P G K K T P G Q Q K Q G E S S S E Q S	44

Alignments were generated by SR (Pedersen 1993). The EM164 surface residues that come within 5? of a CDR are underlined.

H. **Construction of humanized EM164 genes**

[170] The ten surface residue changes for EM164 (Table 7) were made using PCR mutagenesis techniques as described above. Because eight of the surface residues for CLL 1.69 were not within 5? of a CDR, these residues were changed from murine to human in all versions of humanized EM164 (Tables 8 and 9). The two light chain surface residues that were within 5? of a CDR (Kabat positions 3 and 45) were either changed to human or were retained as murine. Together, these options generate the four humanized versions of EM164 that were constructed (Figures 22 and 23).

[171] Of the four humanized versions, version 1.0 has all 10 human surface residues. The most conservative version with respect to changes in the vicinity of the CDR is version 1.1, which retained both of the murine surface residues that were within 5? of a CDR. All four humanized EM164 antibody genes were cloned into an antibody expression plasmid (Figure 16) for use in transient and stable transfections.

TABLE 8 - Residue changes for versions 1.0-1.3 of humanized EM164 antibody

Changes in all versions

Light Chain: muQ18 to huP18; muS67 to huA67

Heavy Chain: muQ5 to huV5; muL11 to huV11; muE61 to huQ61; muK64 to huQ64; muR65 to huG65; muA106 to huQ106

huEM164 changes

	Light Chain aa3		Light Chain aa45		Total 5A
	Mu	hu	mu	hu	Mouse Res
v1.0		V		R	0
v1.1	L		K		2
v1.2	L			R	1
v1.3		V	K		1

I. Comparison of the affinities of humanized EM164 antibody versions with murine EM164 antibody for binding to full-length IGF-I receptor and to truncated IGF-I receptor alpha chain

[172] The affinities of the humanized EM164 antibody versions 1.0-1.3 were compared to those of murine EM164 antibody through binding competition assays using biotinylated full-length human IGF-I receptor or myc-epitope tagged truncated IGF-I receptor alpha chain, as described above. Humanized EM164 antibody samples were obtained by transient transfection of the appropriate expression vectors in human embryonic kidney 293T cells, and antibody concentrations were determined by ELISA using purified humanized antibody standards. For ELISA binding competition measurements, mixtures of humanized antibody samples and various concentrations of murine EM164 antibody were incubated with indirectly captured biotinylated full-length IGF-I receptor or myc-epitope tagged truncated IGF-I receptor alpha chain. After equilibration, the bound humanized antibody was detected using a goat-anti-human-Fab'$_2$-antibody-horseradish peroxidase conjugate. Plots of ([bound murine Ab]/[bound humanized Ab]) *vs* ([murine Ab]/[humanized Ab]), which theoretically yield a straight line with slope = ($K_{d\ \mathrm{humanized\ Ab}} / K_{d\ \mathrm{murine\ Ab}}$), were used to determine the relative affinities of the humanized and murine antibodies.

[173] An exemplary competition assay is shown in Figure 11. An Immulon-2HB ELISA plate was coated with 100 µL of 5 µg/mL streptavidin per well in carbonate buffer at ambient temperature for 7 h. The streptavidin-coated wells were blocked with 200 µL of blocking buffer (10 mg/mL BSA in TBS-T buffer) for 1 h, washed with TBS-T buffer and incubated with biotinylated IGF-I receptor (5 ng per well) overnight at 4°C. The wells containing indirectly

captured biotinylated IGF-I receptor were then washed and incubated with mixtures of humanized EM164 antibody (15.5 ng) and murine antibody (0 ng, or 16.35 ng, or 32.7 ng, or 65.4 ng, or 163.5 ng) in 100 μL blocking buffer for 2 h at ambient temperature and were then incubated overnight at 4°C. The wells were then washed with TBS-T buffer and incubated with goat-anti-human-Fab'$_2$-antibody-horseradish peroxidase conjugate for 1 h (100 μL; 1 μg/mL in blocking buffer), followed by washes and detection using ABTS/H_2O_2 substrate at 405 nm.

[174] The plot of ([bound murine Ab]/[bound humanized Ab]) *vs* ([murine Ab]/[humanized Ab]) yielded a straight line (r^2 = 0.996) with slope (= $K_{d\ \mathrm{humanized\ Ab}} / K_{d\ \mathrm{murine\ Ab}}$) of 0.52. The humanized antibody version 1.0 therefore bound to IGF-I receptor more tightly than did murine EM164 antibody. Similar values for the gradient, ranging from about 0.5 to 0.8, were obtained for competitions of versions 1.0, 1.1, 1.2 and 1.3 of humanized EM164 antibodies with murine EM164 antibody for binding to full-length IGF-I receptor or to truncated IGF-I receptor alpha chain, which indicated that all of the humanized versions of EM164 antibody had similar affinities, which were all better than that of the parent murine EM164 antibody. A chimeric version of EM164 antibody with 92F? C mutation in heavy chain showed a slope of about 3 in a similar binding competition with murine EM164 antibody, which indicated that the 92F? C mutant of EM 164 had a 3-fold lower affinity than did murine EM164 antibody for binding to IGF-I receptor. The humanized EM164 v1.0 antibody showed a similar inhibition of IGF-I - stimulated growth and survival of MCF-7 cells as did the murine EM164 antibody (Figure 24). The inhibition of serum-stimulated growth and survival of MCF-7 cells by humanized EM164 v1.0 antibody was similar to the inhibition by murine EM164 antibody.

TABLE 9

Segment	Light Chain	Heavy Chain
FR1	1-23 (with an occasional residue at 0, and a deletion at 10 in V_{λ} chains)	1-30 (with an occasional residue at 0)
CDR1	24-34 (with possible insertions numbered as 27A, B, C, D, E, F)	31-35 (with possible insertions numbered as 35A, B)
FR2	35-49	36-49
CDR2	50-56	50-65 (with possible insertions numbered as 52A, B, C)
FR3	57-88	66-94 (with possible insertions numbered as 82A, B, C)
CDR3	89-97 (with possible insertions numbered as 95A, B, C, D, E, F)	95-102 (with possible insertions numbered as 100A, B, C, D, E, F, G, H, I, J, K)
FR4	98-107 (with a possible insertion numbered as 106A)	103-113

The Kabat numbering system is used for the light chain and heavy chain variable region polypeptides of the different versions of the EM164 Ab. The amino acid residues are grouped into Framework (FR) and Complementarity Determining Regions (CDR) according to position in the polypeptide chain.

Taken from Kabat et al. *Sequences of Proteins of Immunological Interest,* Fifth Edition, 1991, NIH Publication No. 91-3242

J. **Process of providing improved anti-IGF-I-receptor antibodies starting from the murine and humanized antibody sequences described herein:**

[175] The amino acid and nucleic acid sequences of the anti-IGF-I receptor antibody EM164 and its humanized variants were used to develop other antibodies that have improved properties and that are also within the scope of the present invention. Such improved properties include increased affinity for the IGF-I receptor. Several studies have surveyed the effects of introducing one or more amino acid changes at various positions in the sequence of an antibody, based on the knowledge of the primary antibody sequence, on its properties such as binding and level of expression (Yang, W. P. et al., 1995, *J. Mol. Biol.*, 254, 392-403; Rader, C. et al., 1998, *Proc. Natl. Acad. Sci. USA*, 95, 8910-8915; Vaughan, T. J. et al., 1998, *Nature Biotechnology*, 16, 535-539).

[176] In these studies, variants of the primary antibody have been generated by changing the sequences of the heavy and light chain genes in the CDR1, CDR2, CDR3, or framework regions, using methods such as oligonucleotide-mediated site-directed mutagenesis, cassette mutagenesis, error-prone PCR, DNA shuffling, or mutator-strains of *E. coli* (Vaughan, T. J. et al., 1998, *Nature Biotechnology*, 16, 535-539; Adey, N. B. et al., 1996, Chapter 16, pp. 277-291, in *"Phage Display of Peptides and Proteins"*, Eds. Kay, B. K. et al., Academic Press). These methods of changing the sequence of the primary antibody have resulted, through the use of standard screening techniques, in improved affinities of such secondary antibodies (Gram, H. et al., 1992, *Proc. Natl. Acad. Sci. USA*, 89, 3576-3580; Boder, E. T. et al., 2000, *Proc. Natl. Acad. Sci. USA*, 97, 10701-10705; Davies, J. and Riechmann, L., 1996, *Immunotechnolgy*, 2, 169-179; Thompson, J. et al., 1996, *J. Mol. Biol.*, 256, 77-88; Short, M. K. et al., 2002, *J. Biol. Chem.*, 277, 16365-16370; Furukawa, K. et al., 2001, *J. Biol. Chem.*, 276, 27622-27628).

[177] By a similar directed strategy of changing one or more amino acid residues of the antibody, the antibody sequences described in this invention can be used to develop anti-IGF-I receptor antibodies with improved functions, such as antibodies having suitable groups such as free amino groups or thiols at convenient attachment points for covalent modification for use, for example, in the attachment of therapeutic agents.

K. Alternative expression system for murine, chimeric and other anti-IGF-I receptor antibodies

[178] The murine anti IGF-I receptor antibody was also expressed from mammalian expression plasmids similar to those used to express the humanized antibody (above). Expression plasmids are known that have murine constant regions including the light chain kappa and heavy chain gamma-1 sequences (McLean et al., 2000, *Mol Immunol.*, 37, 837-845). These plasmids were

designed to accept any antibody variable region, such as for example the murine anti-IGF-I receptor antibody, by a simple restriction digest and cloning. Additional PCR of the anti-IGF-1 receptor antibody was usually required to create the restriction compatible with those in the expression plasmid.

[179] An alternative approach for expressing the fully murine anti-IGF-I receptor antibody was to replace the human constant regions in the chimeric anti-IGF-I receptor antibody expression plasmid. The chimeric expression plasmid (Figure 16) was constructed using cassettes for the variable regions and for both the light and heavy chain constant regions. Just as the antibody variable sequences were cloned into this expression plasmid by restriction digests, separate restriction digests were used to clone in any constant region sequences. The kappa light chain and gamma-1 heavy chain cDNAs were cloned, for example, from murine hybridoma RNA, such as the RNA described herein for cloning of the anti-IGF-1 antibody variable regions. Similarly, suitable primers were designed from sequences available in the Kabat database (see Table 10). For example, RT-PCR was used to clone the constant region sequences and to create the restriction sites needed to clone these fragments into the chimeric anti-IGF-I receptor antibody expression plasmid. This plasmid was then used to express the fully murine anti-IGF-I receptor antibody in standard mammalian expression systems such as the CHO cell line.

TABLE 10 - Primers designed to clone the murine gamma-1 constant region and murine kappa constant region respectively.

Murine Constant Region Primers		
Primer name	Primer Sequence	SEQ ID NO:
MuIgG1 C3endX	TTTTGAGCTCTTATTTACCAGGAGAGTGGGAGA GGCTCTT	45
MuIgG1 C5endH	TTTTAAGCTTGCCAAAACGACACCCCCATCTGTCTAT	46
MuIgKap C3endB	TTTTGGATCCTAACACTCATTCCTGTTGAAGC	47
MuIgKap C5endE	TTTTGAATTCGGGCTGATGCTGCACCAACTG	48

The primers were designed from sequences available in the Kabat database (Johnson, G and Wu, T.T. (2001) Nucleic Acids Research, 29: 205-206).

Statement of Deposit

[180] The hybridoma that makes murine EM164 antibody was deposited with the American Type Culture Collection, PO Box 1549, Manassas, VA 20108, on June 14, 2002, under the Terms of the Budapest Treaty and assigned ATCC accession number PTA-4457.

[181] Certain patents and printed publications have been referred to in the present disclosure, the teachings of which are hereby each incorporated in their respective entireties by reference.

[182] While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one of skill in the art that various changes and modifications can be made thereto without departing from the spirit and scope thereof.